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The Shadow Value of Unconventional Monetary Policy

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and Nicola Pavanini

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We quantify how central bank unconventional monetary policy, in the form of funding facilities, reduced the banking sector's intrinsic fragility in the euro area in 2014-2021. We estimate a micro-structural model of imperfect competition in the banking sector that allows for multiple equilibria with bank runs, banks' default and contagion, and central bank funding. Our framework incorporates demand and supply for insured and uninsured deposits, for loans to firms and households, and borrowers' default. We use confidential granular data for the euro area banking sector, including information on banks' borrowing from the European Central Bank (ECB). We document the presence of alternative equilibria with run-type features, but also that central bank interventions exerted a crucial role in containing this risk. Our counterfactuals show that, on average across equilibria, a 1 percentage point reduction in the ECB lending rate leads to a 1.4 percentage points reduction in banks' default probability.

JEL Classification: E44, E52, E58, G01, G21, L13

Keywords: Central bank policies, bank runs, multiple equilibria, Imperfect Competition, structural estimation

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Eurosystem.

The Shadow Value of Unconventional Monetary Policy*

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February 2022

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We quantify how central bank unconventional monetary policy, in the form of funding facilities, reduced the banking sector’s intrinsic fragility in the euro area in 2014-2021. We estimate a micro-structural model of imperfect competition in the banking sector that allows for multiple equilibria with bank runs, banks’ default and contagion, and central bank funding. Our framework incorporates demand and supply for insured and uninsured deposits, for loans to firms and households, and borrowers’ default. We use confidential granular data for the euro area banking sector, including information on banks’ borrowing from the European Central Bank (ECB). We document the presence of alternative equilibria with run-type features, but also that central bank interventions exerted a crucial role in containing this risk. Our counterfactuals show that, on average across equilibria, a 1 percentage point reduction in the ECB lending rate leads to a 1.4 percentage points reduction in banks’ default probability.

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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 unconventional monetary policy, in the form of 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 €2.2 trillions, corresponding to over 18% 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 the shadow value of central bank's interventions, that is what would have happened in the absence of these policies.

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 unconventional monetary policy 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). Modeling 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 shadow value of such policy interventions.

The model is estimated with mostly three 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 2014-2021, which covered almost all of the ECB funding to banks with a peak take up at €2.2 trillions. 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 300 banks resident in the euro area from August 2007 to July 2021. 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 quality of bank loans’ portfolios and 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 64 banks for 168 months from August 2007 to July 2021, covering 13 euro area countries (Austria, Belgium, France, Germany, Greece, Ireland, Latvia, Lithuania, Italy, Portugal, Slovakia, Spain, and the Netherlands). The banks in our sample represent over 50% 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 depositors are considerably more price sensitive than uninsured depositors, with demand elasticities of 0.7 and 0.2, respectively. As expected, our estimates show that uninsured deposits' market shares are decreasing with banks' default probabilities, while we find that insured deposits' market shares react very mildly to banks' idiosyncratic risks. The presence of some sensitivity to bank risk also for insured deposits can be explained by the possible perceived solvability issues for 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. Crucially, this type of cross-bank contagion mechanism can be grasped only in a micro-structural framework, such as ours, that models individual banks' behavior. As expected, we find a negative demand elasticity for loans, with households being more sensitive than firms, and find that borrowers' expected default rates are increasing in loan interest rates, consistent with evidence of either adverse selection or moral hazard.

In terms of documenting multiple equilibria under the actual policy rate, our main findings can be summarized as follows. We show that on average banks' default probabilities are 9 percentage points higher in the alternative equilibria relative to the realized ones. This implies that in those alternative equilibria banks need to compensate their default risk to depositors with higher deposit rates and increase their reliance on central bank funding. The extra funding that banks can collect also maps into lower loan rates. We also document that the distribution of banks' riskiness in the alternative equilibria is characterized by a significantly thicker right tail, representing a higher risk of bank runs, which predominantly involves banks that already had a high level of riskiness in the observed equilibrium.

We complete our analysis with a series of counterfactual exercises, where we simulate scenarios with higher or lower central bank policy rates, and quantify the effect of these changes on the main outcomes of our model. We show that 1 percentage point increase in the policy rate increases on average banks' default probability by about 1.4 percentage points. We also investigate the impact of such change on the country-year weighted average and weighted standard deviation of banks' riskiness, with weights given by banks' assets, to capture the effect on the average stability if a country's banking system as well as on its volatility. We find that one percentage point increase in the policy rate increase the mean and standard deviation of banks' default risk by around 3 and 2 percentage points, respectively. We also find evidence of an asymmetric effect depending on whether the policy rate increases or decreases relative to the realized one, with policy rate increases having a significantly larger effect on the mean and standard deviation of banks' default probabilities. Last, we document that one percentage point increase in the policy rate reduces total welfare by about €22bn, equivalent to a 15% drop relative to the baseline, mostly caused by a decrease in banks' franchise value and higher expected deposit insurance costs.

Related Literature. A number of empirical studies of central bank liquidity injections, based

on granular datasets and on a difference-in-differences 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 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 (Kojien & Yogo 2016), asset demand (Kojien & Yogo 2019), deposits (Ho & Ishii 2011, Xiao 2020), commercial loans (Crawford et al. 2018, Ioannidou, Pavanini & Peng 2022, Darmouni 2020), and mortgages (Benetton 2021, Robles-Garcia 2020). A recent paper by Wang, Whited, Wu & Xiao (2022) 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 & Vuilleme (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 non-fundamental risk 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

¹For the euro area see, for example, Carpinelli & Crosignani (2018), Jasova, Mendicino & Supera (2018), Andrade, Cahn, Fraise & 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).

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 “vulnerable” 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, 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 Since 2008 there have been four types of unconventional monetary policy interventions based on refinancing operations.

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 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 (MROs).

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 by the collateral requirements. While the central bank balance sheet was protected by the adoption of haircuts, which depended on the degree of liquidity of the assets pledged, the subsequent revision of the collateral policy substantially relaxed the collateral constraints existing for banks in accessing those funding facilities.⁵ The interest rate

²See Rostagno, Altavilla, Carboni, Lemke, Motto, Saint Guilhem & Yiangou (2021) 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-vulnerable 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-). It 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.

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 also were conceived so as to avoid some of the side effects experienced with the previous operations.⁶ Due to these reasons, these Targeted Longer-Term Refinancing Operations (TLTROs) are the main focus of our paper. They were announced in June 2014 (TLTRO I), in March 2016 (TLTRO II), and in March 2019 (TLTRO III). In between the 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 and III) differed.⁷ Even though borrowing limits were in place, they were not perceived as necessarily binding in case of systemic shocks because there was an expectation that in such instances they would have been relaxed.

Finally, the pandemic brought forth, in March and April 2020, a series of re-calibrations of TLTRO III, expanding its borrowing limits, maturity, and early repayment options. Moreover, these re-calibrations consisted in an even lower pricing, which then encompassed a transitory period where the minimum achievable TLTRO III rate, subject to a milder lending performance criterion, was as low as -1% . The re-calibrations were accompanied by further relaxation of collateral requirements and a series of additional longer-term operations to bridge the gap between announcements of the measures and the actual operations, as well as a series of Pandemic Emergency Longer-Term Refinancing Operations (PELTROs) which acted as a further backstop for those banks whose business models did not allow for meaningful participation to TLTROs.⁹

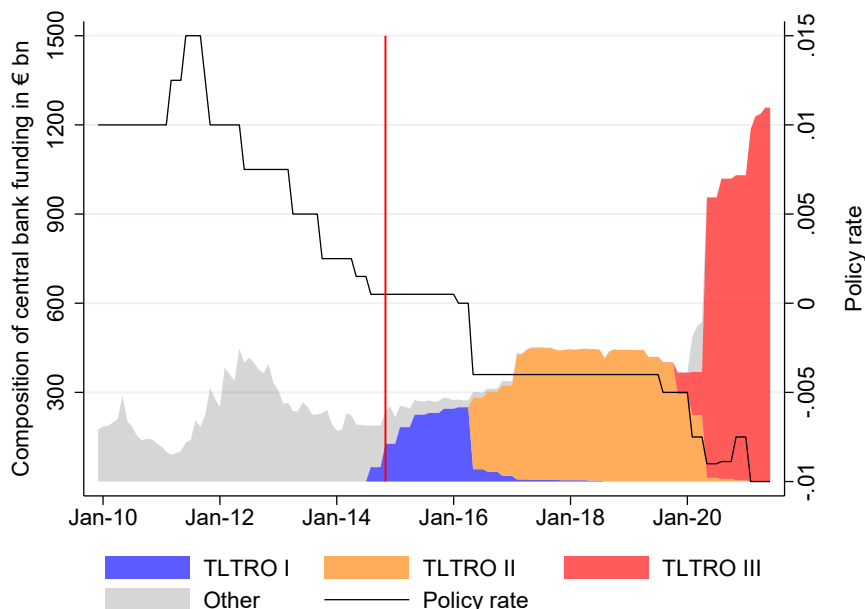
Figure 1 reports the time series evolution of the total amount of ECB funding since 2010, with a breakdown across each of the operations described above, as well as the policy rate that was applied. The level of take up is not necessarily related to the degree of stabilization provided by monetary policy. It is so only conditional on the absence of runs. However, as pointed out above, the simple existence of a lender of last resort, or even just the expectation of it, may avert uncoordinated equilibria. This is why a structural model admitting multiple equilibria is needed to be able to make a comprehensive assessment of the role played by monetary policy in sustaining financial stability.

⁶See Albertazzi, Barbiero, Marqués-Ibañez, Popov, Rodriguez D’Acri & Vlassopolous (2020) for a comparative review of the papers assessing the financial stability spillover of these and other unconventional monetary policy measures.

⁷TLTRO 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 The original pricing design of TLTRO III, settled in July 2019, was similar to TLTRO II’s, with the difference of a 10 basis points spread over MRO rate and DFR, which was later waived in September 2019 right before the first TLTRO III operation (together with a further DFR cut to -0.5%).

⁹See Barbiero, Boucinha & Burlon (2021) for a description of TLTRO III and the related collateral easing measures.

Figure 1: ECB FUNDING AND POLICY RATE WITHIN OUR SAMPLE



Note: TLTRO I, II, and III correspond to the Targeted Longer-Term Refinancing Operations announced respectively in June 2014, March 2016, and March 2019. Other corresponds to the sum of Marginal Lending Facility (MLF), Main Refinancing Operations (MROs), Longer-Term Refinancing Operations (LTROs, including the bridge operations announced in March 2020), Fine-Tuning Operations (FTOs) and Pandemic Emergency Longer-Term Refinancing Operations (PELTROs). Policy rate is the borrowing rate applied to refinancing operations over time. This figure is based on our sample of banks, which corresponds to roughly 50% of overall loan and deposit volumes, and this proportion is also reflected in the amount of ECB funding that our sample covers.

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 300 banks resident in the euro area from August 2007 to July 2021. 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. Third, we gather data on banks' Credit Default Swaps (CDS) from Datastream and on firms' Probabilities of Default (PDs) from Supervisory Reports by the Single Supervisory Mechanism of the ECB. Fourth, we add information on bank profitability and Non-Performing Loans (NPLs) from SNL Financial and Bureau van Dijk's BankScope. Lastly, we have granular information on bank's participation in ECB's lending operations and deposits in ECB's deposit facility and current account from ECB's administrative reports.

The merge of our rich data yields a representative sample of the euro area banking sector, consisting of an unbalanced panel of 64 banks for 168 months from August 2007 to July 2021, covering 13 euro area countries (Austria, Belgium, France, Germany, Greece, Ireland, Latvia, Lithuania, Italy, Portugal, Slovakia, Spain, and the Netherlands). The banks in our sample represent over 50% 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.

Table 1: SUMMARY STATISTICS

	Obs.	Mean	St.Dev.	Min	p25	p50	p75	Max
Uninsured Deposits								
Deposit Volume (€bn)	8,295	15.96	19.01	0.00	3.04	8.15	21.86	114.28
Deposit Rate (%)	8,295	0.41	0.69	-0.58	0.02	0.11	0.47	4.70
Market Share (%)	8,295	10.63	9.60	0.00	1.64	8.69	17.87	40.71
Insured Deposits								
Deposit Volume (€bn)	8,295	40.46	51.03	0.01	9.13	22.15	55.71	418.70
Deposit Rate (%)	8,295	0.43	0.64	-0.51	0.03	0.18	0.51	5.00
Market Share (%)	8,295	9.45	9.73	0.00	1.39	6.41	14.19	43.08
Loans to NFCs								
Loan Volume (€bn)	8,295	26.97	28.83	0.30	5.93	15.41	40.70	167.91
Lending Rate (%)	8,295	2.66	1.48	-0.23	1.58	2.25	3.38	10.06
Market Share (%)	8,295	9.59	9.39	0.03	1.32	6.56	15.80	41.58
Loans to Households								
Loan Volume (€bn)	8,295	34.42	46.97	0.17	7.36	17.56	42.45	370.97
Lending Rate (%)	8,295	3.55	1.75	0.03	2.10	3.32	4.59	10.31
Market Share (%)	8,295	9.22	9.18	0.01	1.45	6.09	14.61	43.48
CDS Spread (%)	8,295	1.68	2.50	0.13	0.60	0.93	1.66	42.41
Banks' Default Prob (%)	8,295	2.64	3.64	0.21	0.98	1.52	2.69	51.85
Borrowers' Default Prob (%)	8,295	2.04	1.49	0.07	1.19	1.61	2.30	9.02
Avg Lending Rate (%)	8,295	3.14	1.50	0.20	1.91	2.86	4.09	9.58
EONIA (%)	8,295	0.12	0.93	-0.48	-0.36	-0.14	0.25	4.30
Sovereign Rate Spread (%)	8,295	1.96	2.47	-0.35	0.71	1.32	2.45	45.96
ROA (%)	8,295	0.25	0.89	-6.56	0.14	0.34	0.59	2.29
Excess Liquidity Holdings (%)	8,295	3.52	6.14	-0.09	0.00	0.71	4.60	50.88
Securities Holdings (%)	8,295	7.58	5.75	0.00	3.53	6.47	10.45	31.40
Deposit Ratio (%)	8,295	38.86	20.18	0.00	24.19	38.41	53.42	82.71
NPL Ratio (%)	8,295	6.20	6.67	0.42	2.46	4.09	6.96	42.49
Loss Given Default (%)	8,295	27.39	7.63	0.00	22.66	27.53	31.37	52.92
Net Position with CB (€bn)	8,295	-0.35	14.96	-131.55	-1.67	0.00	3.80	76.91
CB Policy Rate (%)	8,295	0.24	1.05	-1.00	-0.40	0.05	0.75	4.25
Other Net Balance (€bn)	8,295	5.32	25.91	-105.57	-5.41	1.36	12.54	169.83
Other Borrowing Rate (%)	8,295	2.08	2.69	-0.71	0.52	1.42	3.15	46.32

Note: Unbalanced panel of 64 banks for 168 months from August 2007 to July 2021, covering 13 EA countries (AT, BE, DE, ES, FR, GR, IE, IT, LT, LV, NL, PT, SK). Avg Lending Rate refers to the weighted average of lending rates to NFCs and Households that is used to estimate the loan default model.

For the deposit demand model we use each bank's market share of the domestic market of deposits,

at the month-country level.¹⁰ For the uninsured deposits, we use deposits of domestic corporate clients (overnight, agreed maturity, redeemable at notice), and the bank’s composite interest rate on corporate deposits (weighted average of the interest rates across the segments available in the IMIR dataset). For the insured deposits, we use the deposits of domestic household clients (overnight, agreed maturity, redeemable at notice), and the bank’s composite interest rate on households’ deposits (weighted average of the interest rates across the segments available in the IMIR dataset). 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 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 11 percent in the case of uninsured deposits and 9 percent in the case of insured deposits. Deposit rates are close to zero in most countries, reaching at maximum levels slightly below 5 percent. Some deposit rates are negative, with a few reaching levels below the minimum of the DFR in the sample period, at -0.6 percent. The average interest rate on insured and uninsured deposits is around 0.4 percent.

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 loans to domestic corporate clients, and the bank’s interest rate on new corporate loans excluding overdrafts. For loans to households, we use the loans to domestic households, and the bank’s interest rate on new household loans excluding overdrafts. The market of loans to NFCs is roughly as concentrated as the market of loans to households, with average shares around 10 and 9 percent, respectively. Shares in some smaller countries can reach up to over 40 percent, similarly to the deposit markets. Loan rates hover around 3 to 4 percent on average, and can reach 10 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).¹¹ The average CDS spread in our dataset is 168 basis points, but can reach peaks of over 4,200 basis points during the sovereign debt crisis. Under our assumptions, these peaks correspond to a sizable risk-neutral probability of bank default of 50 percent.

We measure borrowers’ default with the probability of default on performing exposures reported in the Supervisory Reports of the Single Supervisory Mechanism of the ECB. In our sample, this probability is on average 2 percent and can reach over 9 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 loans to the non-financial private sector.

In our regressions we control for a series of time-varying characteristics at the bank level. We include bank’s ROA to proxy for profitability, the ratio of excess liquidity over assets to measure the exposure to the negative interest rate policy and the level of liquidity, the ratio of securities holdings over assets for the exposure to the capital gains from asset purchases by the ECB and the level of collateral, the ratio of deposit over assets to proxy for the business models and the

¹⁰Both deposit and loan market shares are calculated based on the total volume of each month-country banking sector, not only based on our sample of banks.

¹¹We use a 5% risk free rate and bank-month specific recovery rates.

exposure to the frictions emerging from the zero lower bound, and the NPL ratio as a proxy of the quality of the loan portfolio. All controls are considered with a one month lag. 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 banks' loss given default from the Supervisory Reports, the net position of each bank vis-à-vis the ECB (borrowing minus deposits) as well as the policy rate that they were required to pay when borrowing from the ECB. To complete the summary of banks' balance sheets, we include the net balance of the other components of banks' assets and liabilities, and the interest rate on these net balances as proxied by the 10-year domestic sovereign yield.

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 Hortaçsu, 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. Our framework is static and characterized by stationary pure strategy Bayesian Nash equilibria, where banks compete and decide to default within each period, not across periods. The combination of endogenous banks' default due to 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 of banks, depositors and firms. For instance, if depositors expect a bank to default, their expectations will be self-fulfilling, causing demand of mostly uninsured deposits for that bank to diminish, which can only 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 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. This multiplicity based on depositors' beliefs is not eliminated by the presence of a central bank offering liquidity, as the funding it provides is usually constrained by borrowers' availability of suitable collateral.

Note that ours is not a model with bank runs in a narrow sense, because we do not have maturity transformation. However, our mechanism is not different from standard models of bank runs

(Diamond & Dybvig 1983). In fact, in our model a similar strategic complementarity emerges, because the withdrawal of some deposits increases the risk for other depositors. This is not because the bank is forced to liquidate (at a loss) long term illiquid projects, but simply because the withdrawals increase banks' funding costs.

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.¹² We allow not only uninsured depositors, but also insured ones to be sensitive to banks' fragility, to capture any costs that insured depositors might face in case of bank's default, as well as potential delays in the implementation of the deposit insurance scheme.

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 2021), 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

¹²Our 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.

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 have observations with negative rates. We found that none of these nonlinearities are statistically significant, possibly reflecting the presence of a negative effective lower bound below the negative values reached by deposit rates in the sample. We 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 similar way as demand for deposits. 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 :

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

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:

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

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,¹³ 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

¹³We 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.

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:

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

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 banks, and financial liabilities. While the costs faced by the banks on the first two elements of their liabilities are endogenously determined within our model, for the third one, which is introduced to match banks' assets, the cost is exogenously given, and we assume to be determined in international capital markets. We set the amount and interest rate on this latter source as fixed across our counterfactuals. On the other hand, banks' assets are represented by two main components. The first are loans granted to households and firms, while the second are any other source of assets. As for the case of liabilities, the last element is exogenously given and included to match banks' assets in the data.

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

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

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}^C the amount that bank j borrows from the central bank, which decides on a common rate P_t^C .¹⁴ C_{jmt}^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 stochastic 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 $1 - w_{jmt}^L$.¹⁵ We let banks' returns to be defined as:

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

where $M_{mt}^* S_{jmt}^* = w_{jmt}^L (M_{mt}^F S_{jmt}^F + M_{mt}^H S_{jmt}^H) + (1 - w_{jmt}^L) (M_{mt}^I S_{jmt}^I + M_{mt}^N S_{jmt}^N)$. 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:

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

where the equity value next period is determined by the expected value of banks' returns R_{jmt} conditional on survival, times their survival probability. This means that we are not explicitly assuming that banks have any equity. 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 $M_{mt}^L S_{jmt}^L = M_{mt}^F S_{jmt}^F + M_{mt}^H S_{jmt}^H$ and $\lambda(\cdot)$ is the inverse Mills ratio.¹⁶ 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'

¹⁴Note that in some cases we can have $M_{jmt}^B = M_{mt}^F S_{jmt}^F + M_{mt}^H S_{jmt}^H - M_{mt}^I S_{jmt}^I - M_{mt}^N S_{jmt}^N - M_{jmt}^C < 0$, 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.

¹⁵In our current estimation and counterfactual exercises we are setting $w_{jmt}^L = 0.45$. This degree of cost sharing is calculated based on an exercise whereby operating costs are regressed on deposit and lending volumes, to capture the relative importance of each element in driving the dependent variable.

¹⁶The formula for the inverse Mills ratio is $\lambda\left(-\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}}\right) = \frac{\phi\left(\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}}\right)}{\Phi\left(\frac{\bar{C}_{jmt} - \mu_{jmt}}{\sigma_{jmt}}\right)}$.

default probabilities perceived by depositors can be self fulfilling, generating panic-based runs as in Diamond & Dybvig (1983) and Goldstein & Pauzner (2005).

Before observing the realization of the costs C_{jmt} , banks 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:

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

where:

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

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 $C_{jmt}^{\mathcal{I}}$, $C_{jmt}^{\mathcal{F}}$, $C_{jmt}^{\mathcal{C}}$, μ_{jmt} , σ_{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:

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

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 instruments 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 for 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 five 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:

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

Last, the estimation for borrowers’ default is based on the following regression equation:

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

We use the set of instruments of equation (14) also in equation (15) and (16).

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 A.1, A.2, and A.3. 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 price-elastic, just as in the case of 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. We do in fact find that banks’ default probabilities have no significant effect on demand for insured deposits, as reported in column 2 of Table 2.

Price elasticities between the two deposit types are significantly different. In terms of magnitudes, the price elasticity is around 23 percent for uninsured deposits and 67 percent for insured deposits at the level of a 5 percent market share of the domestic market and a 1 percent interest rate. Moreover, with a 5 percent share in the domestic market, uninsured deposits’ demand declines by 2 percentage points for a 1 percentage point increase in the default probability.

We report the estimates for the loan demand in columns 3 and 4 of Table 2. Similarly to deposit markets, we find that households are more sensitive to loan interest rates than firms, with a price elasticity of 14 for households and of 4 for firms.

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 1.5 percent increase in the aggregate lending rate, which roughly

corresponds to 1 standard deviation in our sample, leads to a 4 basis points increase in borrowers' default. Considering that the standard deviation of the latter is 1.5 percent, the default equation describes a mechanism that explains over 3 percent of the unconditional variation in borrowers' default (gross of bank observables and bank and country-time fixed effects).

Table 2: DEPOSIT AND LOAN DEMAND, BORROWERS' DEFAULT

	DEPOSITS		Firms	LOANS	
	Uninsured	Insured		Households	Default
Interest Rate	24.49*** (3.32)	70.48*** (4.00)	-4.63*** (1.39)	-14.57*** (1.61)	2.41*** (0.76)
Bank Default Probability	-2.35*** (0.93)	-0.25 (0.62)			
Bank Controls	Yes	Yes	Yes	Yes	Yes
Bank FE	Yes	Yes	Yes	Yes	Yes
Country-Month FE	Yes	Yes	Yes	Yes	Yes
Observations	8,295	8,295	8,295	8,295	8,295
R-squared	0.031	0.076	0.061	-0.017	0.015

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. Bank controls include ROA, excess liquidity holdings, securities holdings, deposit ratio, and NPL ratio.

4.2 Model Fit

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 a 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}^F of granting loans to NFCs relative to households, and the extra cost C_{jmt}^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 A.1). 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 lending which, based on the model, is implicit in the pricing of loans, seems to be strongly countercyclical (Figure A.2). 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 A.3).

The variance of costs of borrowers' default σ_{jmt} follows a long-term downward trend (Figure A.4). This implies, together with Figure A.2, 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.

The opportunity cost of issuing insured deposits as opposed to uninsured ones C_{jmt}^I became permanently lower after the crisis (Figure A.6), possibly reflecting stronger appetite for this source of funding, but also gradual perceived improvements in the institutional framework, ultimately leading to the banking union. The distribution became also more asymmetric, with a thicker left tail. The opportunity cost of lending to NFCs as opposed to households C_{jmt}^F did not change significantly over time (Figure A.7). Instead, costs of central bank funding C_{jmt}^C gradually increased relative to other funding sources, despite the decrease in policy rates (Figure A.8), possibly reflecting market stigma associated with these funding sources.

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 country-year combination, given the estimated demand elasticities and the policy rate. 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 predominantly 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 eight yearly snapshots of the eight largest countries, covering the main 30 banks. Two preliminary remarks can be done before discussing the properties of the set of equilibria. First, one important consistency check performed was to verify 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. Second, the analysis below will 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.¹⁷ What is instead not arbitrary and relevant 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.

To begin, Table 3 summarizes some descriptive statistics on the distribution of alternative equilibria, which includes the realized ones, across vulnerable and non-vulnerable countries. Those summary 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 net of deposits with the ECB, and changes in depositors' and borrowers' surplus, banks' profits, and total welfare between the realized equilibrium and each alternative one. At the bottom, Table 3 reports the average number of equilibria per country-year combinations. As expected, bank default probabilities are higher in vulnerable countries than in non-vulnerable ones. This is not reflected into a difference in deposit rates across the two groups of countries, thanks to a higher reliance on central bank funding in vulnerable countries. Moreover, higher loan rates in vulnerable economies reflect both higher levels of observable and unobservable credit risk. Surpluses and profits of the model agents, expressed as difference relative to the observed equilibrium, are consistent with the level of the relevant interest rates.

Table 3: DESCRIPTIVE STATISTICS ACROSS COUNTRIES, YEARS, ALTERNATIVE EQUILIBRIA

	Vulnerable Countries			Non-Vulnerable Countries		
	Mean	Median	Std Dev	Mean	Median	Std Dev
Bank Default Probability (%)	14.47	2.07	18.84	12.78	1.07	15.41
Total Deposit Volume (€bn)	561.61	410.75	445.42	1089.95	648.77	861.46
Deposit Rates (%)	6.36	0.02	9.33	6.27	0.25	8.64
Total Loan Volume (€bn)	500.25	572.92	251.78	613.77	641.81	245.12
Loan Rates (%)	0.63	2.33	3.81	0.17	1.48	2.83
Borrowers Default Probability (%)	1.95	1.75	1.15	1.30	1.27	0.37
Δ Depositors' Surplus (€bn)	43.03	-0.40	71.21	61.86	-0.07	93.47
Δ Borrowers' Surplus (€bn)	9.55	0.00	21.11	9.16	-0.20	19.11
Δ Banks' Profits (€bn)	-99.90	0.41	158.32	-191.30	0.10	264.89
Δ Total Welfare (€bn)	-47.33	-3.45	73.27	-120.29	-5.28	171.07
Net position vis-à-vis ECB (%)	2.12	9.36	30.51	-16.28	-8.79	36.00
N of Equilibria per Country-Year		12.73			32.67	

Note: Descriptive statistics are calculated across 8 countries, 8 years, and all equilibria, with breakdown by 5 vulnerable countries (IT, ES, GR, IE, PT) and 3 non-vulnerable countries (DE, FR, NL). An equilibrium is counted as a country-year combination. This means that uniqueness (N of equilibria per country-year equal to 1) would imply 40 equilibria in vulnerable countries and 24 equilibria in non-vulnerable countries.

We next document in Table 4 the differences in several outcomes between the realized and alternative equilibria. We do so regressing each outcome on bank-year fixed effects and a dummy for alternative equilibria, which captures the average difference between realized and alternative equilibria holding fixed any time varying bank level factors. We find that on average bank default probabilities are 9

¹⁷Relatedly, 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.

percentage points higher in the alternative equilibria relative to the realized ones. To compensate depositors for their higher default risk, banks offer deposit rates between 5 and 4 percentage points higher, which leads to larger deposit market shares, and increase their share of funding from the ECB on average by 21 percentage points. This higher availability of funds implies that banks, in order to invest their increased funding, offer loan rates between 2 and 3 percentage points lower, which translates in larger market shares in lending markets as well. The mechanism explaining the reduction in loan rates is the following. As banks experience a costs increase on their liability side, due to their higher default risk, they try to compensate this profit loss with lower loan rates. While this decreases profits per borrower, it allows them to lend to more firms and households, and reduce borrowers' default risk, which in equilibrium leads to larger profits on the asset side.

Table 4: COMPARISON BETWEEN REALIZED AND ALTERNATIVE EQUILIBRIA

	Banks'	Deposit Rates		Loan Rates		Share CB
	Default Prob	Uninsured	Insured	Firms	Households	Funding
Alternative Equilibrium	0.09*** (0.01)	0.05*** (0.00)	0.04*** (0.00)	-0.02*** (0.00)	-0.03*** (0.00)	0.21*** (0.01)
Bank-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	6,222	6,222	6,222	6,222	6,222	6,222
R-squared	0.195	0.124	0.142	0.172	0.200	0.229

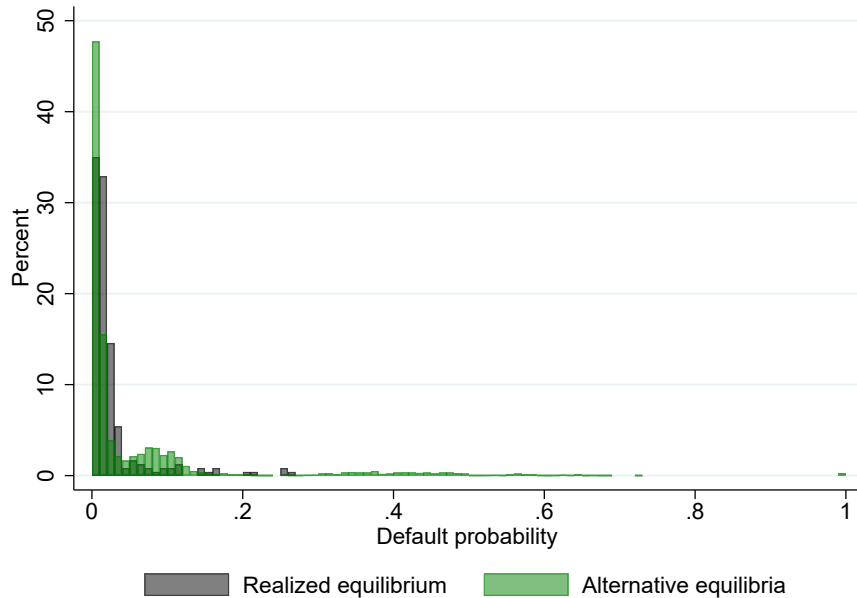
Note: Standard errors in parentheses are clustered at the bank-year level, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

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.¹⁸ 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 around 1%, expressed by the median default probability in the bank-year distribution of the realized equilibrium, is the same as the corresponding quantity in the bank-year-equilibrium distribution. 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 75th percentile of the two distributions rises from 2% to 7%, and the 95th from 11% up to 40%. 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 comparing the left tail of the two distributions: the 25th percentile in the bank-year-equilibria distribution is 0.02%, smaller than the corresponding quantity for the distribution in the realized equilibrium at 0.8%.

The interpretation of the findings above is that over the sample period scrutinized, the banking

¹⁸We 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 (Table 7).

Figure 2: DISTRIBUTION OF REALIZED AND ALTERNATIVE DEFAULT PROBABILITIES



Note: Pooled bank-year observations. “Realized equilibrium” is the data (December observations from 2014 to 2020 plus July 2021 for the balanced panel of 30 banks). “Alternative equilibria” are the sequences of values compatible with FOCs and estimated parameters.

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.

We complement the graphical evidence on tail risk from Figure 2 with some regression analysis in Table 5, where we show how banks’ default probabilities for high risk banks varies in the alternative equilibria relative to the realized one. We define high risk banks in three ways, as those that have a default probability respectively above the 50th, 75th, and 95th percentile of the distribution in the realized equilibrium. More specifically, in Table 5 we display the results of a regression of bank’s default probabilities on dummies for high risk bank interacted with dummies for alternative equilibria. We find that banks with default risk above the 75th and 95th percentile have on average a higher default probability in the alternative equilibria respectively of 8.3 and 29.2 percentage points, consistent with evidence of significant tail risk in the alternative equilibria and of positive correlation between fundamental and non-fundamental risk. This implies that weaker banks are more exposed to the occurrence of adverse equilibria.

6 Counterfactuals

In what follows we look at the response of key bank-level and country-level variables across equilibria in counterfactual scenarios, in which the policy rates at which intermediaries can borrow from the central bank are either higher (up to two percentage points higher every year from 2014 to 2019)

Table 5: TAIL RISK IN THE ALTERNATIVE VS REALIZED EQUILIBRIA

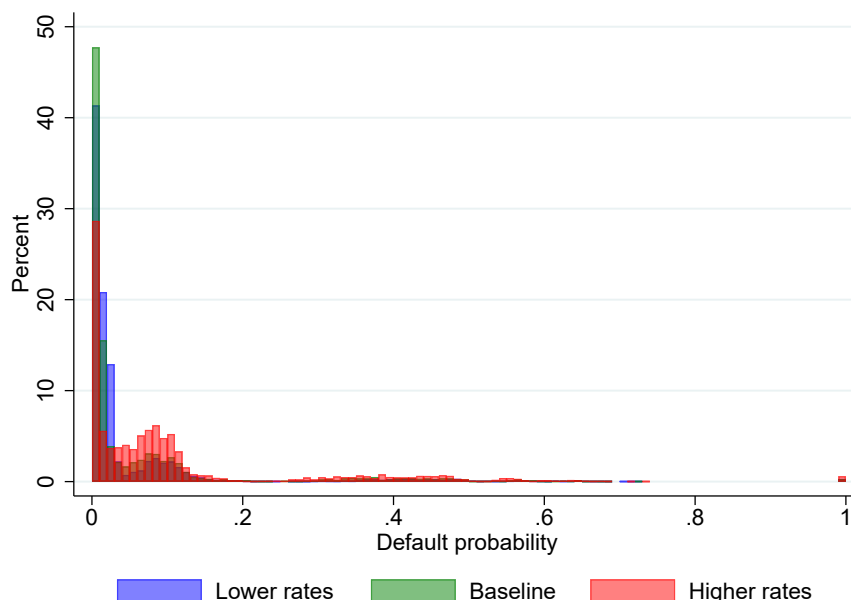
	Banks' Default Prob
High Risk Bank (above 50 th pctile) × Alternative Equilibrium	-0.002 (0.006)
High Risk Bank (above 75 th pctile) × Alternative Equilibrium	0.083*** (0.020)
High Risk Bank (above 95 th pctile) × Alternative Equilibrium	0.292*** (0.070)
Bank-Year FE	Yes
Alternative Equilibrium FE	Yes
Observations	6,222
R-squared	0.209

Note: Standard errors in parentheses are clustered at the bank-year level, *** p<0.01, ** p<0.05, * p<0.1.

or lower (up to two percentage points lower every year from 2014 to 2019).¹⁹ First, as shown in Figure 3, 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.

¹⁹We consider four counterfactual levels of the policy rate, namely plus and minus 1 and 2 percentage points compared to the baseline level. We have conducted several robustness checks with different alternative policy rates, such as plus or minus 1 basis point, 50 basis points, 1.5 percentage points, 2.5 percentage points and 3 percentage points. All qualitative results hold across calibrations.

Figure 3: DISTRIBUTION OF DEFAULT PROBABILITY ACROSS POLICY RATE SCENARIOS



Note: Pooled bank-year observations. “Baseline rates” correspond to equilibria with actual policy rates. “Lower rates” (“Higher rates”) correspond to equilibria with 1 and 2 percentage point lower (higher) policy rates than actual ones.

Table 6 reports how the main model outcomes presented in Table 4 change across different levels of policy rates at the bank level. We regress each model outcome on the policy rate, which includes the baseline level and all the counterfactual values, and control for bank-year fixed effects. We find that 1 percentage point increase in the policy rate increases banks’ default probability by about 1.4 percentage points, drives up deposit rates by around 2 percentage points (more for uninsured deposits than for insured ones) and loan rates by 11 basis points, and reduces borrowing from the central bank by over 2.3 percentage points. These results quantify the important role of unconventional monetary policy via the TLTRO refinancing operations, not only to reduce banks’ default risk, but also to provide them with cheap liquidity that eases pressure on deposits and can reduce cost of credit for households and firms.

Table 6: COMPARISON ACROSS EQUILIBRIA WITH DIFFERENT POLICY RATES

	Banks’ Default Prob	Deposit Rates		Loan Rates		Share CB Funding
		Uninsured	Insured	Firms	Households	
Policy Rate	1.40*** (0.11)	2.07*** (0.09)	1.86*** (0.08)	0.11** (0.05)	0.11** (0.05)	-2.32*** (0.35)
Bank-Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	28,031	28,031	28,031	28,031	28,031	28,031
R-squared	0.167	0.153	0.176	0.116	0.136	0.187

Note: Standard errors in parentheses are clustered at the bank-year level, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

Table 7 shows the effect of a change in policy rate on the weighted average and weighted standard deviation of banks' default probabilities within a country-year combination, with weights given by banks' assets. These two outcome measures are meant to capture the average stability of a country's banking system as well as its volatility. We regress these two variables on country-year fixed effects, on the policy rate across all our scenarios, but also on the policy rate interacted with dummies for an increase or a decrease in the policy rate relative to the baseline to test for asymmetric responses. We find that one percentage point increase in the policy rate increase the mean and standard deviation of banks' default risk by around 3 and 2 percentage points, respectively. We also find evidence of an asymmetric effect depending on whether the policy rate increases or decreases relative to the realized one, with policy rate increases having a significantly larger effect on the mean and standard deviation of banks' default probabilities.

The last column of Table 7 shows that 1 percentage point increase in the policy rate reduces total welfare by almost €22bn on average across countries and years, which corresponds to approximately a 15% drop relative to the baseline. We construct this measure of welfare as the sum of depositors' surplus, borrowers' surplus, the discounted sum of banks' franchise value, the aggregate deposit insurance costs and banks' bankruptcy costs, and report in Appendix C the detailed formulae. The breakdown of the effect of the policy rate on each welfare component is presented in Table A.4, which shows that a higher policy rate favors depositors, as they obtain higher deposit rates, but harms banks' franchise value and has almost no effect on borrowers.

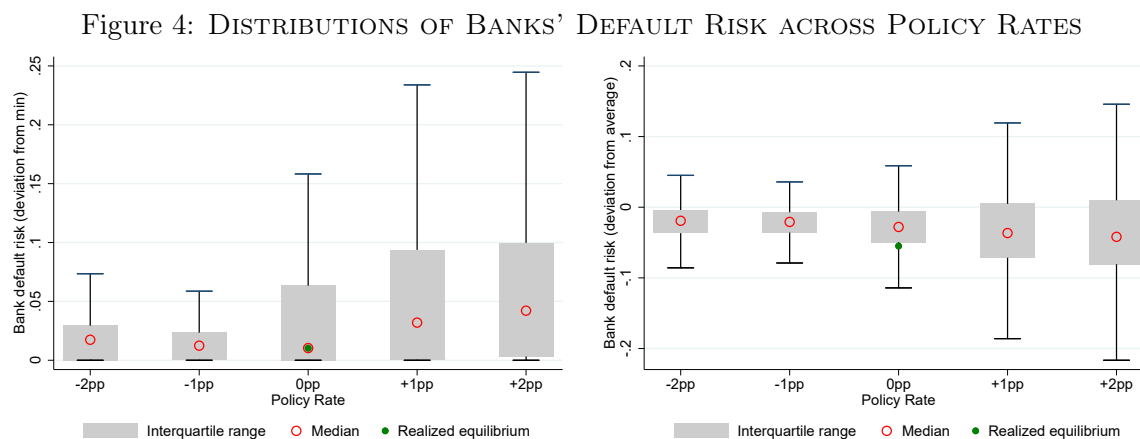
These results show that the ECB intervention played a significant role at reducing the average instability of euro area countries' banking systems, but also its volatility and the overall welfare level. The asymmetric effect on banks' default risk of an increase or decrease in the policy rate can be interpreted as follows. Banks under the actual policy rate, as reported in Table 3, have a low default probability, which implies that they are close to the lower bound of zero in their default risk. As a consequence, while a decrease in the policy rate, which will contribute to a reduction in banks' default risk, is bound in its effect, an increase in the policy rate can almost unboundedly rise banks' default risk.

Table 7: IMPACT OF POLICY RATE ON NON-FUNDAMENTAL RISK AND WELFARE

	Banks' Default Probability				Total Welfare
	Weighted Average		Weighted Std Dev		
Policy Rate	3.01*** (0.48)		1.96*** (0.29)		-21.94*** (4.89)
Policy Rate × Increase		5.45*** (0.94)		3.21*** (0.56)	
Policy Rate × Decrease		1.01** (0.55)		0.93*** (0.36)	
Country-Year FE	Yes	Yes	Yes	Yes	Yes
Observations	5,755	5,755	5,755	5,755	5,755
R-squared	0.261	0.270	0.121	0.129	0.374

Note: The unit of observation is a country-year-equilibrium combination. Total Welfare is measured in billions of euros. Standard errors in parentheses are clustered at the country-year level, *** p<0.01, ** p<0.05, * p<0.1.

Last, we present our counterfactual results also in Figure 4, where we display the distributions of banks’ default risk across all the policy rate values that we simulated. The red empty circles represent the median of each distribution, while the green solid dots for the baseline policy rate (“0pp” in the graph) represent the observed equilibrium in the data. The left figure, which displays the distribution of banks’ default probabilities across bank-year-equilibrium combinations in deviation from the bank-year minimum, indicates that a higher policy rate leads to a higher median bank’s default probability and a higher dispersion. These results reflect the direct impact on banks’ solidity of changes in the cost of central bank funding, which we know is disproportionate for the upper tail institutions (the weaker ones). However, these findings also reflect the ability of monetary policy to eradicate equilibria with runs. This is visible in the right figure, which shows the distribution of banks’ default probabilities across bank-year-equilibrium combinations in deviation from the bank-year average, and as such is cleaned from the first direct funding cost channel. Lower (higher) rates are associated with a visibly smaller (larger) levels of dispersion across equilibria.



Notes: The box plots refer to the distribution, for each level of the policy rates and across bank-year-equilibrium combinations, of banks’ default probabilities in deviation from the bank-year minimum (left figure) and in deviation from the bank-year average (right figure). Horizontal bars report the whiskers of the distribution.

7 Conclusion

We provide quantitative evidence of the impact that central bank unconventional monetary policy, in the form of 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 2014-2021.

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, non-linear impact in mitigating both fundamental and non-fundamental risk.

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Appendix A - Additional Tables and Figures

Table A.1: DEPOSIT DEMAND

	Uninsured		Insured	
	OLS	IV	OLS	IV
Interest Rate	13.91*** (2.73)	24.49*** (3.32)	42.06*** (3.00)	70.48*** (4.00)
Bank Default Prob	-2.24*** (0.26)	-2.35*** (0.39)	-0.66** (0.30)	-0.25 (0.62)
ROA	-5.86*** (0.62)	-5.70*** (0.65)	4.16*** (1.35)	4.62*** (1.24)
Excess Liquidity Holdings	0.86*** (0.14)	0.85*** (0.14)	0.17 (0.18)	0.12 (0.18)
Securities Holdings	-0.00 (0.13)	0.10 (0.13)	1.05*** (0.13)	1.34*** (0.15)
Deposit Ratio	0.11 (0.15)	0.12 (0.15)	0.54*** (0.14)	0.54*** (0.14)
NPL Ratio	0.14 (0.17)	0.22 (0.17)	0.87*** (0.21)	1.04*** (0.23)
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	8,295	8,295	8,295	8,295
R-squared	0.985	0.031	0.984	0.076

Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table A.2: LOAN DEMAND

	NFCs		Households	
	OLS	IV	OLS	IV
Interest Rate	-2.13*** (0.75)	-4.63*** (1.38)	-2.51** (1.19)	-14.57*** (1.61)
ROA	-5.82*** (0.62)	-5.86*** (0.62)	-6.58*** (0.63)	-5.22*** (0.71)
Excess Liquidity Holdings	-0.38*** (0.12)	-0.38*** (0.12)	-0.06 (0.15)	0.01 (0.15)
Securities Holdings	-0.51*** (0.12)	-0.55*** (0.12)	-0.32* (0.17)	-0.17 (0.17)
Deposit Ratio	-1.08*** (0.15)	-1.07*** (0.15)	-0.48** (0.22)	-0.52** (0.22)
NPL Ratio	1.00*** (0.15)	1.03*** (0.15)	1.29*** (0.25)	1.49*** (0.25)
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	8,295	8,295	8,295	8,295
R-squared	0.981	0.061	0.979	-0.017

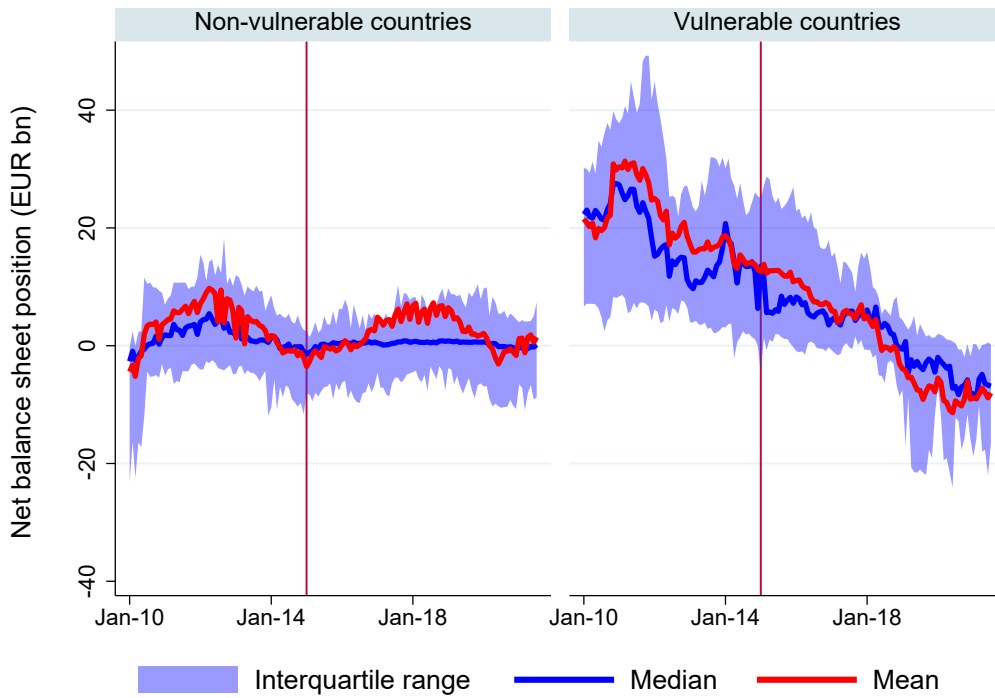
Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1.

Table A.3: DEFAULT EQUATION

	Dep Var in OLS	Level IV	Transform IV
Avg Lending Rate	0.03*** (0.01)	0.03* (0.01)	2.41*** (0.76)
ROA	-0.01* (0.01)	-0.01 (0.01)	1.09** (0.45)
Excess Liquidity Holdings	0.00*** (0.00)	0.00*** (0.00)	0.56*** (0.08)
Securities Holdings	-0.01*** (0.00)	-0.01*** (0.00)	-0.80*** (0.14)
Deposit ratio	0.00*** (0.00)	0.00*** (0.00)	-0.39*** (0.08)
NPL ratio	0.00 (0.00)	0.00 (0.00)	0.36*** (0.11)
Bank FE	Yes	Yes	Yes
Country-Month FE	Yes	Yes	Yes
IV - Monetary Policy	No	Yes	Yes
IV - Sovereign Risk	No	Yes	Yes
Observations	8,295	8,295	8,295
R-squared	0.971	0.015	0.025

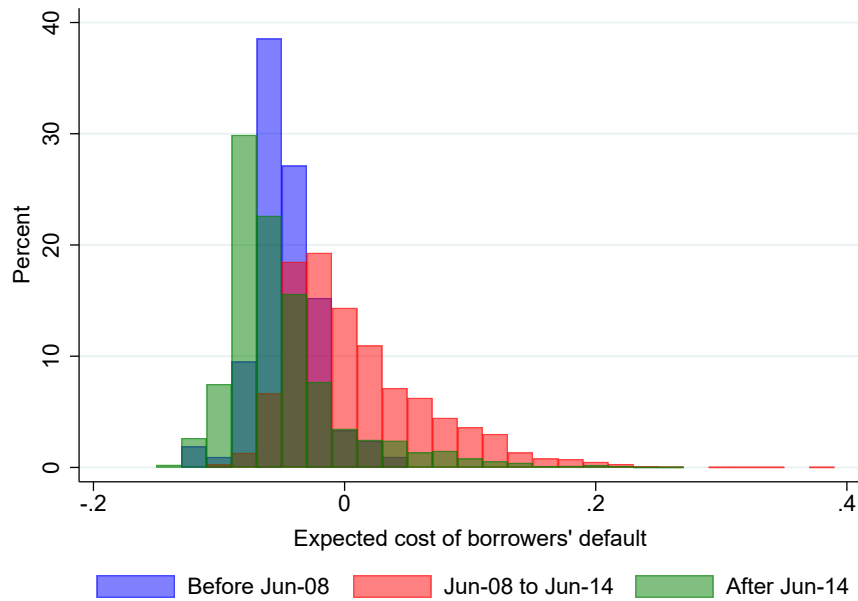
Note: Robust standard errors in parentheses, *** p<0.01, ** p<0.05, * p<0.1. The transform of borrowers' default probability is $\log([\cdot]) - \log(1 - [\cdot])$.

Figure A.1: MODEL-IMPLIED VARIABLES: EVOLUTION OF NET BALANCE SHEET POSITION



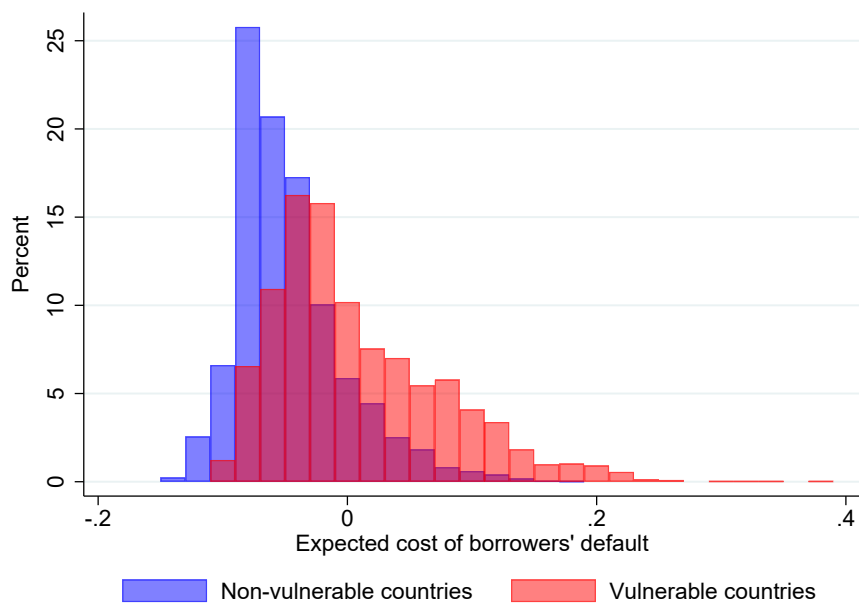
Note: Pooled bank-month observations. “Non-vulnerable countries” include AT, BE, DE, FR, LT, LV, NL, SK. “Vulnerable countries” include IT, ES, GR, IE, PT.

Figure A.2: MODEL-IMPLIED VARIABLES: EXPECTED COST OF BORROWERS’ DEFAULT



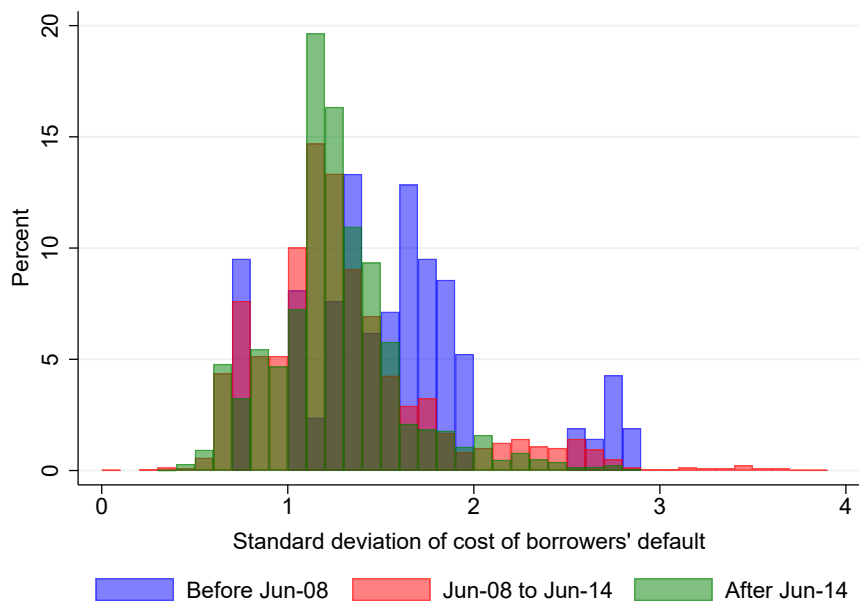
Note: Pooled bank-month observations.

Figure A.3: MODEL-IMPLIED VARIABLES: EXPECTED COST OF BORROWERS' DEFAULT ACROSS COUNTRIES



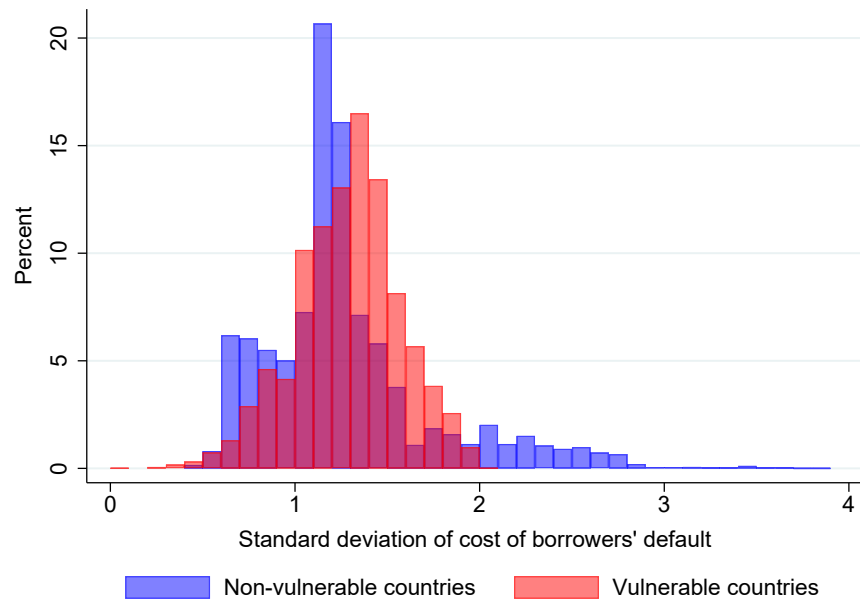
Note: Pooled bank-month observations. “Non-vulnerable countries” include AT, BE, DE, FR, LT, LV, NL, SK. “Vulnerable countries” include IT, ES, GR, IE, PT.

Figure A.4: MODEL-IMPLIED VARIABLES: STANDARD DEVIATION OF COST OF BORROWERS' DEFAULT



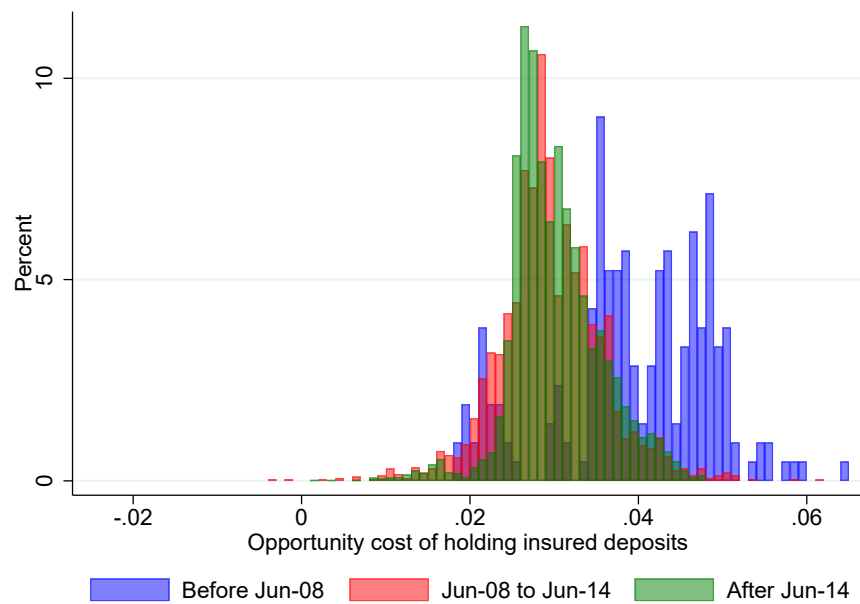
Note: Pooled bank-month observations.

Figure A.5: MODEL-IMPLIED VARIABLES: STANDARD DEVIATION OF COST OF BORROWERS' DEFAULT ACROSS COUNTRIES



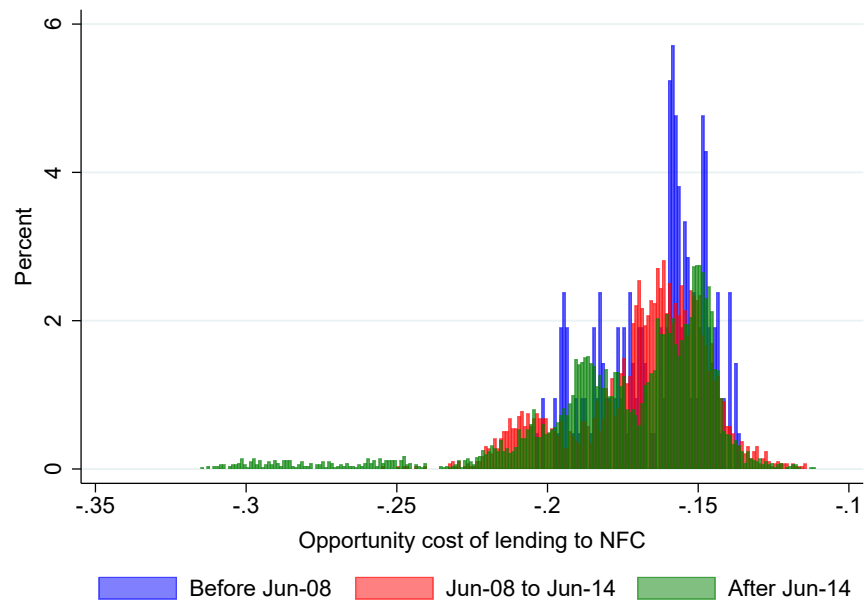
Note: Pooled bank-month observations. “Non-vulnerable countries” include AT, BE, DE, FR, LT, LV, NL, SK. “Vulnerable countries” include IT, ES, GR, IE, PT.

Figure A.6: MODEL-IMPLIED VARIABLES: OPPORTUNITY COST OF INSURED DEPOSITS



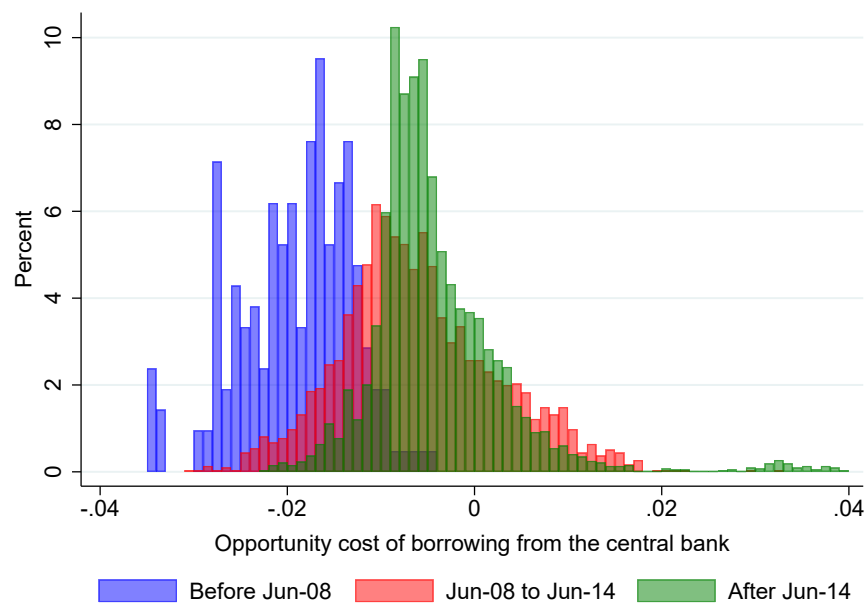
Note: Pooled bank-month observations.

Figure A.7: MODEL-IMPLIED VARIABLES: OPPORTUNITY COST OF LOANS TO NFCs



Note: Pooled bank-month observations.

Figure A.8: MODEL-IMPLIED VARIABLES: OPPORTUNITY COST OF CENTRAL BANK FUNDING



Note: Pooled bank-month observations.

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} .

Appendix C - Welfare Analysis

Our model has three utility maximizing agents: depositors, borrowers and banks. Both depositors and borrowers have standard linear indirect utility functions, as defined in (1) and (3), thus, one can express the welfare of the two agents (in US dollars) respectively as:

$$CS_{mt} = \frac{M_{mt}^{\mathcal{I}}}{|\alpha^{\mathcal{I}}|} \ln \left(\sum_i \exp(\alpha^{\mathcal{I}} P_{imt}^{\mathcal{I}} + \delta_i^{\mathcal{I}} + \zeta_{mt}^{\mathcal{I}} + \xi_{imt}^{\mathcal{I}}) + 1 \right) + \frac{M_{mt}^{\mathcal{N}}}{|\alpha^{\mathcal{N}}|} \ln \left(\sum_j \exp(\alpha^{\mathcal{N}} P_{jmt}^{\mathcal{N}} + \gamma^{\mathcal{N}} F_{jmt} + \delta_j^{\mathcal{N}} + \zeta_{mt}^{\mathcal{N}} + \xi_{jmt}^{\mathcal{N}}) + 1 \right), \quad (28)$$

$$BS_{mt} = \frac{M_{mt}^{\mathcal{H}}}{|\alpha^{\mathcal{H}}|} \ln \left(\sum_i \exp(\alpha^{\mathcal{H}} P_{imt}^{\mathcal{H}} + \delta_i^{\mathcal{H}} + \zeta_{mt}^{\mathcal{H}} + \xi_{imt}^{\mathcal{H}}) + 1 \right) + \frac{M_{mt}^{\mathcal{F}}}{|\alpha^{\mathcal{F}}|} \ln \left(\sum_j \exp(\alpha^{\mathcal{F}} P_{jmt}^{\mathcal{F}} + \delta_j^{\mathcal{F}} + \zeta_{mt}^{\mathcal{F}} + \xi_{jmt}^{\mathcal{F}}) + 1 \right), \quad (29)$$

where CS stands for depositors' surplus, and BS represents borrowers' surplus. For simplicity, the formulae exclude the Euler-Mascheroni constant, which drops out when we compute changes in welfare. We normalize the utility of the outside option to 0, which justifies the addition of 1 in the expressions.

We measure banks' welfare in terms of their annualized equity value as follows:

$$AEV_{mt} = r \sum_b E_b, \quad (30)$$

where the equity value for each bank E_b is backed out from the default condition (11).

When a bank defaults, only a fraction of its assets can be recovered, and the remaining costs are borne by depositors²⁰ Thus, the expected costs of deposit insurance can be expressed as:

$$EIC_{mt} = 0.6 M_{mt}^{\mathcal{I}} \sum_b F_{bmt} s_{bmt}^{\mathcal{I}}. \quad (31)$$

In the event of bankruptcy not only the insured depositors incur losses, as there may be negative externalities that damage the rest of the economy. We proxy that by introducing a 20% bankruptcy costs, defined as:

$$EBC_{mt} = 0.2 \sum_b F_{bmt} (M_{mt}^{\mathcal{I}} s_{bmt}^{\mathcal{I}} + M_{mt}^{\mathcal{N}} s_{bmt}^{\mathcal{N}}). \quad (32)$$

Finally, we compute the change in total welfare as:

$$\Delta W_{mt} = \Delta CS_{mt} + \Delta BS_{mt} + \Delta AEV_{mt} + \Delta EIC_{mt} + \Delta EBC_{mt}. \quad (33)$$

²⁰We assume a 40% recovery rate, in line with Egan et al. (2017).

Note that we do not include central bank's profits in this expression because we do not explicitly model the central bank's objective function.

Table A.4: IMPACT OF POLICY RATE ON WELFARE COMPONENTS

	Depositors' Surplus	Borrowers' Surplus	Banks' Franchise Value	Total Welfare
Policy Rate	23.72*** (3.49)	-0.12 (0.55)	-45.54*** (8.62)	-21.94*** (4.89)
Country-Year FE	Yes	Yes	Yes	Yes
Observations	5,755	5,755	5,755	5,755
R-squared	0.251	0.117	0.296	0.374

Note: The unit of observation is a country-year-equilibrium combination. All dependent variables are measured in billions of euros. Banks' franchise value is defined as the annualized equity value net of deposit insurance costs and bank's bankruptcy costs. Robust standard errors in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.