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Interbank Decisions and Margins of Stability: an Agent-Based Stock-Flow Consistent Approach

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ABSTRACT

This study investigates the functioning of modern payment systems through the lens of banks' maturity mismatch practices, and it examines the effects of banks' refusal to roll over short-term interbank liabilities on financial stability. Within an agent-based stock-flow consistent framework, banks can engage in two segments of the interbank market that differ in maturity, overnight and term. We compare two interbank matching scenarios to assess how bank-specific maturity targets, dependent on the dictates of the Net Stable Funding Ratio, impact the dynamics of the interbank market and the effectiveness of conventional monetary policies. The findings reveal that maturity misalignment between deficit and surplus banks compromises the interbank market's efficiency and increases reliance on the central bank's standing facilities. Monetary policy interest-rate steering practices also become less effective. The study also uncovers a dual stability-based configuration in the banking sector, resembling the segmented European interbank structure. This paper suggests that heterogeneous maturity mismatches between surplus and deficit banks may result in asymmetric funding frictions that might precede credit- and sovereign-risk explanations of interbank tensions. Also, a combined examination of macroprudential tools and rollover-based interbank dynamics can enhance our understanding of how regulatory changes impact the stability of heterogeneous banking sectors.

1. Introduction

Interbank markets play a pivotal role in the financial system, facilitating smooth payment settlements and effective monetary policy transmission. However, these markets are vulnerable to disruptions. The European Sovereign Debt Crisis (SDC) featured a sharp decline in overnight unsecured exchanges (European Central Bank, 2019), which exposed European banks to asymmetric funding frictions, amplifying liquidity imbalances which led to an interbank market *fragmentation* (Bonatti et al., 2021; Al-Eyd and Berkmen, 2013). Reserve-scarce peripheral banks struggled with high funding costs, impacting firms' and households' access to credit (Al-Eyd and Berkmen, 2013), while core-country banks faced a surplus of liquidity, often invested in foreign assets (López and Stracca, 2021). The European Central Bank (ECB)'s response to the overnight market freeze included unconventional measures, yet challenges in restoring the monetary policy transmission mechanism persist (Tropeano, 2019).

Gabrieli and Labonne (2018) highlight two main sources of interbank fragmentation: increased sovereign risks (Cesaratto, 2013; De Santis, 2019) and heightened counterparty credit risks (Eisenschmidt et al., 2018). While central bankers challenge the sovereign-

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based source (Minenna et al., 2018),[1] the credit risk perspective remains predominant behind the ECB's fragmentation index. The existing focus on credit-risk concerns holds during times of crisis but may "blind" monetary authorities.[2] Indeed, it fails to address persistent factors impairing banks' access to the money market in normal times, which could also anticipate credit risks' materialization. Maturity mismatches expose banks to the risk of rollover – or funding liquidity risk[3] – which acts as an endogenous source of financial instability (Acharya et al., 2011; Acharya and Skeie, 2011; Anand et al., 2012; Ferrara et al., 2019). Moreover, shock propagation seems stronger when banks suffer from a cascade of funding shortfalls rather than a cascade of defaults (Ferrara et al., 2019). Empirical evidence also suggests that banks use the interbank market to manage their duration gap, which is seen as a major source of risk (Bluhm et al., 2016). As such, the risk of rollover stands out as a powerful predictor of interbank tensions, making it a crucial factor that cannot be overlooked (Bechtel et al., 2022; Reale, 2023).

Research on interbank networks has increasingly focused on the interplay between banks' funding shortages and financial stability, with agent-based models (ABM) exploring the implications of varying maturity profiles in banks' portfolios (Bargigli et al., 2015; Montagna and Kok, 2016; Liu et al., 2018; Halaj and Kok, 2015). However, a formal analysis of banks' funding asymmetries deriving from divergent rollover-based maturity preferences is still missing.

This paper aims to fill this gap by (i) examining the functioning of the interbank market when banks can choose the maturity structure of their funding sources and (ii) analyzing how maturity shocks affect the clearing operations of a theoretical payment system. The main objective of this paper is to provide an alternative narrative of the EZ's interbank fragmentation based on rollover-induced frictions. To this aim, this article develops an Agent-Based Stock-Flow Consistent (AB-SFC) analysis of a complex evolving system in line with recent modeling practices (see Caiani et al., 2018; Gräbner-Radkowitsch et al., 2022; Schütz, 2022, among others). On the one hand, Agent-Based Models (ABM) are best suited to model such a framework, given the high complexity and heterogeneity of money markets (Wolski and van de Leur, 2016; Berndt et al., 2019). On the other hand, Stock-Flow Consistent (SFC) applications à la Godley and Lavoie (2006) allow for the interaction between the real and financial sides of the economy, whose institutions are explicitly modeled (Ioannou, 2018). By combining these two methods and modeling a heterogeneous banking sector, this model mimics the functioning of TARGET 2 (T2) and captures the interaction of the various maturity-based interbank segments. In this paper, two groups of banks interact with each other (Reale, 2022). While one group grants credit only to households – i.e., commercial banks – business banks provide loans to firms to finance production. Therefore, for every consumption and/or wage payment decision, banks may suffer from a payment outflow that must be settled in the central bank's money. To do so, banks can access a multilayered unsecured interbank network diversified by maturity. The interbank network is composed of two segments, overnight and term, to model the behavior of banks when they have "preferences for diversified funding sources in terms of rollover risk" (Halaj and Kok, 2015, p. 2). We model two interbank matching mechanisms to isolate the impact of rollover risk on interbank dynamics. The "Baseline" matching protocol features deficit banks looking for partners that can fully accommodate interbank requests in volumes and maturity. Instead, the "Maturity" scenario introduces endogenous target financial ratios deriving from the guidelines imposed by the *Net Stable Funding Ratio* (NSFR) of Basel III, such that interbank matching depends on the residual maturities of assets and liabilities in the balance sheets of surplus and deficit banks.

The outline of this article is as follows. Section 2 reviews the literature related to this study. Section 3 introduces the general characteristics of the model along with the mathematical formalization of banks' behaviors and interbank market matching mechanisms. The next section (section 4) describes the simulation strategy and discusses the experiments and the main results. The last section concludes.

2. Related literature

This paper is closely related to contributions investigating the interbank market through network analyses or multi-agent perspectives. In this body of literature, specific attention is given to articles examining interbank segments diversified by maturity, considering banks' funding liquidity risk and maturity mismatches. Halaj and Kok (2015) provide a combination of agent-based modeling and theoretical sequential games to study how interbank networks endogenously emerge and impact contagion risk. The authors adopt a *portfolio optimization* perspective and allow banks to choose their preferred funding structures to limit exposures to the risk of rollover.[4] However, the authors do not explicitly model the maturity structure of interbank assets and liabilities, i.e., they assume that all the items in banks' balance sheets have the same residual maturity, which differs from our approach. Bargigli et al. (2015) analyze maturity-varying credit relations by focusing on a series of interbank layers that provide a more accurate representation of the interbank market. Along these lines, Montagna and Kok (2016) adopt a multi-layered interbank network analysis to investigate systemic risk in the highly interconnected European financial system. Multiple-segment analyses – such as the one we propose – can thus prevent underestimating shock propagation and financial instability. In contrast to these analyses, though, our

[1] According to the ECB, excess liquidity provision would solve the fragmentation problem (European Central Bank, 2018). Hence, the monetary authority still ignores sovereign-based sources.

[2] The blindness of central bankers has also been appointed in the aftermath of the subprime crisis, as monetary policymakers long ignored the unsustainable trend of house prices (Davies, 2009).

[3] Funding liquidity and rollover risks can be used interchangeably as refraining from rolling over induces funding risk. The risk of rollover derives from banks' (in)ability to re-access the market to pay for already existing debts. Therefore, it arises when lenders refuse to roll-over debtors' loans and make it difficult for borrowers to raise funds (Gauthier et al., 2014).

[4] In this context, rollover risk depends on lending banks' probability of default. When a creditor goes bankrupt, the inability to roll over materializes in the form of funding risk, measured as the variance of the portfolio.

model isolates the effects of rollover risks as we do not account for counterparty credit risk. Liu et al. (2018) inspire our modeling approach to banks' maturity decisions and interbank matching protocols. The authors account for interbank contracts diversified by duration (overnight and short-term), where (i) the formation of interbank links depends on the contract's maturity, and (ii) demand and supply for a specific duration depends on financial targets. However, these targets depend on banks' risk preferences and are not intended to reflect preferences for maturity directly, which are, instead, the focus of our model.

This paper is also linked to the few articles that adopt AB-SFC models and account for interbank market dynamics. Lengnick (2013) build a simple AB-SFC model of a monetary economy where the banking sector is seen as a large decentralized economic system. In their attempt to study the effects of interbank lending on financial stability, the authors reveal the existence of potential instability that follows from the maturity mismatch of assets and liabilities in banks' balance sheets, in line with the focus of our paper. While they model the endogenous creation of money as deriving from "behavioral interactions" (Lengnick, 2013, p. 16), our approach is most closely related to the concept of money being endogenously created by the banking sector *out of thin air*.[5] Schasfoort et al. (2017) incorporate interbank market dynamics within the *benchmark model for macroeconomics* proposed by Caiani et al. (2016). In their AB-SFC framework, interest rates on the credit market depend on the funding costs banks face in the interbank market, similar to our modeling assumptions. However, interbank exchanges do not originate from a payment settlement process. Reissl (2018) adopts a hybrid technique by modeling a disaggregate banking sector – leaving all other sectors in aggregate terms – to study heterogeneous expectations on the credit market. Nevertheless, interbank market behavior is straightforward and overlooks inherently complex dynamics.

In this study, we introduce a new perspective on interbank market fragmentation, focusing on tension generated by rollover processes. Through the use of multi-agent analyses, we explore how banks' maturity preferences in the interbank market influence funding asymmetries, an aspect previously overlooked in existing literature. Our work not only advances but also refines the AB-SFC frameworks. By conceptualizing a theoretical payment system within the banking sector, where banks' decisions have immediate implications for settling real sector transactions, we shed light on how persistent and structural maturity-based issues could perpetuate market fragmentation. Our contribution, therefore, not only enriches the academic discourse but also has significant practical implications for policymakers and financial institutions grappling with market fragmentation challenges.

3. The model

The postulated economy comprises one government, one central bank, and a collection of households, firms, and banks. Households ($hh = 1, 2, ..., N_h$) buy consumption goods from firms, save in the form of banks' deposits (D_{hh}), receive wage payments and dividends, pay taxes to the government and have access to banks' loans (L_{hh}). Firms ($f = 1, 2, ..., N_f$) receive loans (L_f) to finance the production of a homogeneous consumption good and "are assumed to manage their liquidity by holding bank deposits" (Michell, 2014, p. 9) – D_f. The public sector is composed of the government and the central bank. The former collects taxes paid by households and finances its public debt by issuing short-term securities (B) – which are bought by the banking sector (Bb) and, residually, by the central bank (Bcb) – and long-term bonds (B^{lr}) to absorb banks' non-performing loans (NPL). The central bank provides required reserves (HPM), advances (A), and standing facilities that banks can use when interbank exchanges come to a standstill (R^l and R^d).[6] The most detailed part of this model concerns the behavior of banking institutions. The banking sector comprises two collections of banks to resemble the functioning of a potential payment system within an overdraft economy and simulate the operational framework of the European T2. For this reason, commercial banks ($j = 1, 2, ..., N_{bj}$) grant loans only to households, and business banks k ($k = 1, 2, ..., N_{bk}$) provide funds only to firms to finance production. This segmentation of the banking sector mimics the dynamics of a monetized production economy as stylized in Fig. 1. Whenever households buy consumption goods or receive wage payments from firms, the payment flows between these two agents translate into deposit outflows and inflows into banks' balance sheets, whose debt relationship must be cleared through a transfer of reserves in the liability side of the central bank's balance sheet. When banks do not have enough reserves to cover the payment transfer arising from the initial monetary transaction, they access the unsecured interbank market. Two segments of the unsecured interbank market are considered: the overnight and the term one. As such, banks endogenously transform maturity, in line with real-world banking practices (Donaldson and Piacentino, 2022), and we can tackle banks' debt maturity structure decisions as dependent on the level of maturity mismatch.

In each simulation period, these agents interact in four markets: households interact with firms on the consumption goods market; firms and households interact with banking institutions on the credit market; banks and the central bank interact with the government on the market for securities – bills, and bonds; last, the two types of banks interact with each other on the interbank market. While bills market interactions depend on simple quantitative buffers – standard in SFC models – and the government accommodates banks' demand for bonds, the interactions in the credit and goods markets take place through a common matching protocol (Michell, 2014; Caiani et al., 2016; Bargigli et al., 2016; Schasfoort et al., 2017). The mechanism for partners' selection in the credit and goods markets is random at t_0 (Delli Gatti et al., 2010). From the subsequent periods on, demand agents (households and firms) observe the

[5] The endogenous money perspective has gained widespread acceptance among scholars and practitioners (Moore, 1991; Deutsche Bundesbank, 2017; Kauko, 2017). According to this view, banks are not mere intermediaries between savings and investments, but they can grant loans independently of the reserves they hold. Credit money materialises as a simple accounting entry in banks' balance sheets and is thus created *out of thin air* as it is not the by-product of any pre-existing input.

[6] In this paper, we only consider the tools banks can access *at their discretion* to guarantee the stability of their payment flows (Bindseil, 2014). Therefore, we do not aim at modeling open market operations – i.e., main refinancing operations and LTROs – which are instead put forward at the central bank's discretion. We adopt this simplification so as not to overload the model with unnecessary assumptions about the frequency and maturity of the central bank's instruments, which are out of the scope of this paper.

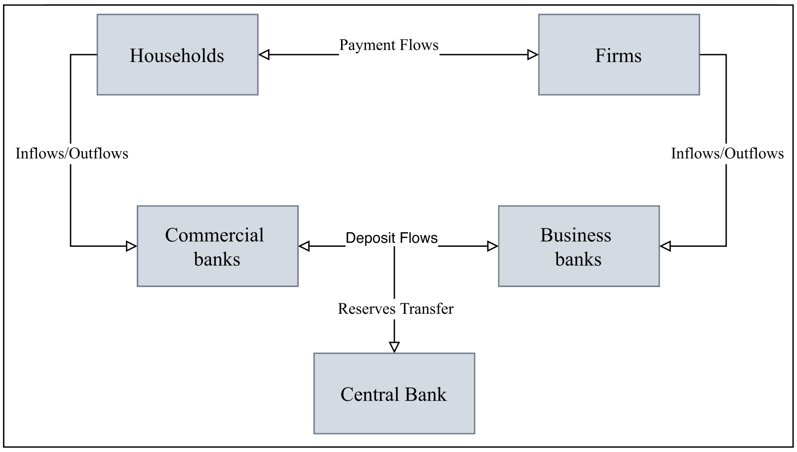

Fig. 1. Monetized Production Economy.

Table 1
Balance sheet matrix.

	Firms	Households	Banks	Government	Central bank	Σ
Capital	$+K$					$+K$
Inventories	$+INV$					$+INV$
Loans	$-L_f$	$-L_h$	$+L$			0
Deposits	$+Df$	$+Dh$	$-D$			0
Bills			$+Bb$	$-B$	$+Bcb$	0
Bonds			$+B^{lr}$	$-B^{lr}$		0
High powered money			$+HPM$		$-HPM$	0
Advances			$-A$		$+A$	0
Lending Facility			$-R^l$		$+R^l$	0
Deposit Facility			$+R^d$		$-R^d$	0
Balance	$-NWf$	$-NWh$	$-NWb$	$+GD$	0	$-(K+INV)$
Σ	0	0	0	0	0	0

interest rates and prices charged by a random subset of supply agents (banks and firms) and decide whether to choose the current supplier or to switch to a new one according to a *probability of switching* partners and an exogenous *intensity of choice* parameter (Delli Gatti et al., 2010; Schasfoort et al., 2017). Banks can exchange interbank funds in two segments diversified by maturity, overnight, and term. We model two interbank matching protocols that allow us to distinguish between a *baseline* and a *maturity-based* scenario. First, we set a "Baseline" matching where banks engage in interbank exchanges with partners who can best accommodate their customers' demand for funds in both segments. Second, we implement a "Maturity" scenario where banks engage in an *active search for counterparties* (Liu et al., 2018) based on the maturities of the exchangeable interbank contracts, see section 3.2.4. The balance sheet matrix – Table 1 – depicts the stocks held by each collection of agents in each sector.[7]

3.1. Sequence of events

At each simulation round, the following order of events takes place:

1. *Pricing:* firms set prices as a markup over past unit direct costs. Banks update the interest rates for loans and deposits according to previous-period funding costs;
2. *Production planning:* firms set their desired level of investments, make production decisions based on expected sales and short-run inventory targets, pay wages, and produce output;
3. *Consumption goods market:* households observe the prices on consumption goods charged by a subset of firms and decide whether to change partner or buy from the previous matched firm. They make consumption decisions based on expected income and pay taxes on wages. If sales exceed output and inventories, consumers are rationed accordingly.
4. *Credit market:* firms and households observe a random subset of banks and forward their loan applications to the bank charging the lowest interest rate. A constant proportion of loans is assumed to be non-performing each period;
5. *Interbank market:* banks update their interbank status – *surplus, deficit* or *neutral* – according to the payment flows arising from their customers' consumption spending and wage payments. Banks engage in interbank transactions on the overnight

[7] The Appendix also provides the transaction flow matrix (Table A.1), which captures the transactions arising from sectoral interactions.

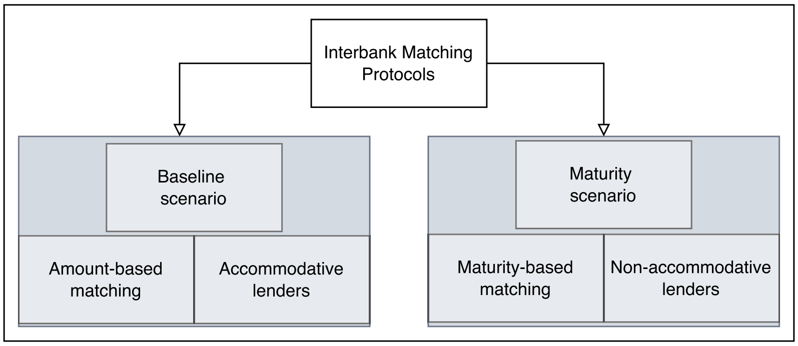

Fig. 2. Interbank matching and scenarios.

and term segments using two matching protocols (see Fig. 2). When interbank transactions freeze, banks can access the central bank's standing facility to acquire the reserves needed or deposit their excess holdings. Banking institutions also update their funding costs based on interbank transactions and their recourse to the lending facility;

6. *Securities market:* the government issues long-term bonds – to absorb banks' non-performing loans – and bills, and the central bank clears the bills market.

The following sections describe agents' behaviors.[8]

3.2. Sectoral equations

3.2.1. Public sector

The government buys a constant fraction $\bar{g}$ of consumption goods at current prices $p_{f,t}$ (Eq. (1)), collects taxes on households' wages (2), issues short-term treasury bills (Eq. (3)) and accommodates banks' demand for long-term bonds (Eq (4)) which are used as a simple bail-out mechanism for non-performing loans (Eq. (5)).

$$G_t = \bar{g} \cdot \sum_{f \in N_f} p_{f,t} \tag{1}$$

$$T_t = \bar{\tau} \cdot \sum_{h \in N_h} W_{h,t} \tag{2}$$

$$B_t \equiv B_{t-1} + G + \bar{i}_b B_{t-1} + \bar{i}_b^{lr} B_{t-1}^{lr} + \Delta NPL_t - T_t - Pcb_t - \Delta B_t^{lr} \tag{3}$$

$$B_t^{lr} = \sum_{j \in N_{bj}} B_{j,t}^{lr} + \sum_{k \in N_{bk}} B_{k,t}^{lr} \tag{4}$$

$$NPL_t = \sum_{j \in N_{bj}} NPL_{j,t} + \sum_{k \in N_{bk}} NPL_{k,t} \tag{5}$$

The central bank clears the bills market residually (Eq. (6)), provides reserves accommodating banks' demand for high-powered money (Eq. (7)) and advances (Eq. (8)), and allows banks to access lending (Eq. (9)) and deposit facilities (Eq. (10)). Profits (Eq. (11)) are distributed to the government.

$$Bcb_t \equiv B_t - \sum_{j \in N_{bj}} Bb_{j,t} - \sum_{k \in N_{bk}} Bb_{k,t} \tag{6}$$

$$HPM_t \equiv \sum_{j \in N_{bj}} HPM_{j,t} + \sum_{k \in N_{bk}} HPM_{k,t} \tag{7}$$

$$A_t \equiv \sum_{j \in N_{bj}} A_{j,t} + \sum_{k \in N_{bk}} A_{k,t} \tag{8}$$

$$R_t^l \equiv \sum_{j \in N_{bj}} R_{j,t}^l + \sum_{k \in N_{bk}} R_{k,t}^l \tag{9}$$

$$R_t^d \equiv \sum_{j \in N_{bj}} R_{j,t}^d + \sum_{k \in N_{bk}} R_{k,t}^d \tag{10}$$

$$Pcb_t \equiv \bar{i}_b Bcb_{t-1} + \overline{icb}^t A_{t-1} + \overline{icb}^l R_{t-1}^l - \overline{icb}^t HPM_{t-1} - \overline{icb}^d R_{t-1}^d \tag{11}$$

[8] All the exogenous variables are denoted with a bar. Subscripts h refer to households, f to firms, and j (k) to commercial (business) banks.

3.2.2. Productive sector

Firms set their prices (Eq. (12)) following a mark-up rule on previous period unit costs, defined as the ratio of current period wages and output (Eq. (13)). Employed workers (Eq. (15)) receive a constant fraction ω of wages (Eq. (14)), which is deposited at the matched business bank $k \in N_{bk}$ (Eq. (16)). Every period, firms compute their expected sales (Eq. (17)) as a convex linear combination of their actual sales s_i (Eq. (18)) and past expectations $s^e_{i,t}$.[9] Firms tend to achieve long-run and short-run inventory targets (Eq. (19), (20)). Current output (Eq. (21)) is a function of expected sales, the short-run inventory target, and past period real inventories (Eq. (22)). As such, production is demand-driven unless firms' sales exceed output and previous real inventories. When this happens, consumers are rationed homogeneously. The flow of firms' inventories adjusts to the difference between output and actual sales, and nominal inventories are computed at current unit costs (Eq. (23)). The amount of loans demanded is defined as an accounting identity issued from the transaction flow matrix at Table A.1 (Eq. (24)), and a constant fraction of loans is non-performing each period (Eq. (25)). Firms hold capital (Eq. (26)), which depreciates at a constant rate δ, and depends on nominal investments (Eq. (27)). Each period, firms invest a constant fraction of past-period capital (Eq. (28)) and make profits that are distributed to households (Eq. (29)).

$$p_{i,t} = UC_{i,t-1} \cdot (1 + \bar{\rho}) \tag{12}$$

$$UC_{i,t} = \frac{W_{i,t}}{y_{i,t}} \tag{13}$$

$$W_{i,t} = \bar{\omega} \cdot N_{i,t} \tag{14}$$

$$N_{i,t} = \frac{y_{i,t}}{\overline{pr}} \tag{15}$$

$$Df_{i,t} = \bar{g}_d W_{i,t-1} \tag{16}$$

$$s^e_{i,t} = \bar{\beta} s_{i,t-1} + (1 - \bar{\beta}) s^e_{i,t-1} \tag{17}$$

$$s_{i,t} = \frac{\bar{g}}{|N_f|} + i_{i,t} + \sum_h c^*_{h,t}, \ \forall h \in N_h \text{ s.t. } \text{link}_{i,h} \neq 0 \tag{18}$$

$$inv^T_{i,t} = \bar{\sigma} \cdot s^e_{i,t} \tag{19}$$

$$inv^e_{i,t} = inv^e_{i,t-1} + \bar{\phi}(inv^T_{i,t} - inv^e_{i,t-1}) \tag{20}$$

$$y_{i,t} = s^e_{i,t} + inv^e_{i,t} - inv_{i,t-1} \tag{21}$$

$$inv_{i,t} = inv_{i,t-1} + y_{i,t} - s_{i,t} \tag{22}$$

$$INV_{i,t} = inv_{i,t} \cdot UC_{i,t} \tag{23}$$

$$Lf_{i,t} \equiv Lf_{i,t-1} + I_{i,t} + \Delta INV_{i,t} + \Delta Df_{i,t} \tag{24}$$

$$NPLf_{i,t} = \bar{l} \cdot Lf_{i,t} \tag{25}$$

$$K_{i,t} = (1 - \bar{\delta}) K_{i,t-1} + I_{i,t} \tag{26}$$

$$I_{i,t} = i_{i,t} \cdot p_{i,t} \tag{27}$$

$$i_{i,t} = \bar{g}_k K_{i,t-1} \tag{28}$$

$$Pf_{i,t} \equiv \sum_h C^*_{h,t} + I_{i,t} + \frac{G_t}{|N_f|} + \Delta INV_{i,t} - W_{i,t} + i^{d*}_{k,t-1} Df_{i,t-1} - i^{l*}_{k,t-1} Lf_{i,t-1}, \ \forall k \in N_{bk} \tag{29}$$

3.2.3. Households sector

Households have a certain amount of disposable income (Eq. (30)) and consume (Eq. (31)) out of (adaptive) expected income (Eq. (32)) and current net wealth (Eq. (33)). They ask for commercial banks' loans (Eq. (34)) to finance nominal consumption (Eq. (35)), and hold deposits residually (Eq. (36)). Similarly to the firms' sector, a constant fraction (l) of current loans turns non-performing each period (Eq. (37)).

$$Yd_{i,t} = W_{i,t} + i^{d*}_{j,t-1} Dh_{i,t-1} + \sum_{j \in N_{bj}} \frac{Pb_{j,t}}{|N_h|} + \sum_{k \in N_{bk}} \frac{Pb_{k,t}}{|N_h|} + \sum_{f \in N_f} \frac{Pf_{f,t}}{|N_h|} - T_{i,t} - i^{l*}_{j,t-1} Lh_{i,t-1} \tag{30}$$

$$c_{i,t} = \bar{\alpha}_1 \frac{Yd^e_{i,t}}{p^*_{f,t}} + \alpha_2 \frac{NWh_{i,t}}{p^*_{f,t}}, \ \forall f \in N_f \text{ s.t. } \text{link}_{i,f} \neq 0 \tag{31}$$

$$Yd^e_{i,t} = Yd^e_{i,t-1} + \bar{\phi}(Yd_{i,t-1} - Yd^e_{i,t-1}) \tag{32}$$

[9] Variables denoted with "$*$" refer to agents x with whom i has established a link ($\text{link}_{i,x} \neq 0$) in the various markets according to the implemented matching protocols.

$$NWh_{i,t} = Dh_{i,t} - Lh_{i,t} \tag{33}$$

$$Lh_{i,t} = \bar{\gamma} \cdot (NWh_{i,t-1} + C_{i,t}) \tag{34}$$

$$C_{i,t} = c_{i,t} \cdot p^*_{f,t}, \ \ \forall f \in N_f \text{ s.t. link}_{i,f} \neq 0 \tag{35}$$

$$Dh_{i,t} \equiv Dh_{i,t-1} + \Delta Lh_{i,t} + Yd_{i,t} - C_{i,t} \tag{36}$$

$$NPLh_{i,t} = \bar{l} \cdot Lh_{i,t} \tag{37}$$

3.2.4. Banking sector

Both types of banks ($i = \{j, k\}$) receive high-powered money from the central bank to meet their reserve requirements, defined as a fixed proportion ($\bar{\mu} + \bar{v}$) of current deposits (Eq. (38)). They buy government bills as a buffer, constrained by the amount the government issues (Eq. (39)). If bills are null, the central bank's advances (Eq. (40)) act as buffer variable (Dafermos, 2012). At each period, a constant proportion of firms' and households' loans is assumed to be non-performing. Non-performing loans (NPL) are transferred to the government through long-term securities (Eq. (41)), and banks' profits (Eq. (42)) are distributed to households.

$$HPM_{i,t} = (\bar{\mu} + \bar{v})D_{i,t} \tag{38}$$

$$Bb_{i,t} = \min(D_{i,t} + NPL_{i,t} + R^l_{i,t} - L_{i,t} - \bar{\mu}D_{i,t} - B^{lr}_{i,t} - R^d_{i,t}, \ \frac{B}{N_b}) \tag{39}$$

$$A_{i,t} = \begin{cases} L_{i,t} + R^d_{i,t} + HPM_{i,t} + B^{lr}_{i,t} - D_{i,t} - NPL_{i,t} - R^l_{i,t} & \text{if } Bb_{i,t} < 0 \\ \bar{v}D_{i,t} & \text{otherwise} \end{cases} \tag{40}$$

$$B^{lr}_{i,t} = NPL_{i,t} \tag{41}$$

$$Pb_{i,t} = i^l_{i,t-1}L_{i,t-1} + \overline{icb}^t HPM_{i,t-1} + \bar{ib}Bb_{i,t-1} + \bar{ib}^{lr}B^{lr}_{i,t-1} + \overline{icb}^d R^d_{i,t-1} - i^d_{i,t-1}D_{i,t-1} - \tag{42}$$

$$- \overline{icb}^t A_{i,t-1} - \overline{icb}^l R^l_{i,t-1}$$

Banks access the interbank market to settle the real sector's transactions as their demand for interbank loans originates from *payment settlement purposes* (Reale, 2022). Banks' roles in the interbank market thus depend on outflows and inflows (Eq. (43)) borne by banks due to the conduct of business in the real sector. Since business and commercial banks have different customers, every consumption decision (C) and wage payment (W) triggers a *reserve adjustment process* that defines the pool of interbank lenders (surplus banks) and borrowers (deficit banks). Commercial (business) banks have a set of households' (firms') customers $S_{i,t} = \{i \mid i \in N_h \text{ and link}_{i,x} \neq 0\}$ ($S_{i,t} = \{i \mid i \in N_f \text{ and link}_{i,x} \neq 0\}$) that is updated every period according to the credit market matching protocol. As such, banks' payment flows are indirectly affected by the interest rates they charge on loans. Banks incurring a payment outflow ($f < 0$) ask for interbank funds (DF) if their change in high-powered money is not enough to smooth the liquidity shock (Eq. (44)). The amount of reserves lending banks can provide on the interbank market (LF) derives from payment inflows ($f > 0$) exceeding their reserve requirements (Eq. (45)).

$$f_{i,t} = \begin{cases} \sum_{i \in S_{i,t}} (C_{i,t} - W_{i,t}) & \text{if } i = \text{commercial} \\ \sum_{i \in S_{i,t}} (W_{i,t} - C_{i,t}) & \text{otherwise} \end{cases} \tag{43}$$

$$DF_{i,t} = |f_{i,t}| - \Delta HPM_{i,t} \tag{44}$$

$$LF_{i,t} = f_{i,t} - \Delta HPM_{i,t} \tag{45}$$

Interbank matching The two banks can interact in the overnight and term segments of the unsecured interbank market. We model two interbank matching mechanisms, thus implementing two comparable scenarios. In the "Baseline" scenario, interbank matching depends on the amounts demanded and supplied, and lenders accommodate their customers' requests for funds and maturity. Instead, when the "Maturity" scenario is active, the interbank matching mechanism follows an *active search for counterparties* (Liu et al., 2018) where borrowing banks search for lenders having the closest maturity preference.

To do so, banks have target financial ratios that reflect their preferences for maturity which result from the maturity mismatch in their balance sheets. While borrowing banks look at their maturity-based borrowing target ratios and decide how much to demand overnight and term, lending banks decide whether and how much to supply in the two segments according to their lending targets. To model target ratios, this study exploits the Net Stable Funding Ratio (NSFR) of Basel III, a macroprudential tool that limits the excessive degree of banks' maturity mismatches characterizing the GFC.[10] The NSFR requires that the total amount of *available stable funds* (long-term liabilities LM) must at least equal the total amount of *required stable funds* (long-term assets AM), that is $\sum_i a_i LM_i \geq \sum_n b_n AM_n$. The concept of *stability* revolves around the expiration dates of assets and liabilities. To do so, the weights a_i and b_n depend on the residual contractual maturities of the items on both sides of banks' balance sheets such that the longer

[10] Maturity mismatches are excessive when a 30 years mortgage is funded every 24 hours (Goodhart and Perotti, 2015).

the maturity, the higher the weight.[11] After some mathematical manipulations, we define a regulatory margin of stability MS that drives banks' maturity choices in the interbank market. According to the regulatory margin of stability, the amount of available stable funds must be at least equal to the amount of required stable funds, that is:

$$\frac{a_m LM}{b_m AM} = MS_{i,t} \geq 1; \tag{a}$$

where (i) AM and LM are unweighted assets and liabilities (Eq. (46)-(47)), (ii) b_m is the fraction of required stable funds over total assets (Eq. (48)), and (iii) a_m is the proportion of available stable funds over total liabilities (Eq. (49)).[12] Please note that (i) interbank assets (IBA) and liabilities (IBL) depend on the interbank exchanges that occurred in the overnight and term segments – defined in equations (62)-(63) – and that (ii) we distinguish between households' medium-term loans and firms' short-term credit when computing the proportion of required stable funds and assigning the corresponding maturity weight.

$$AM_{i,t} = L_{i,t-1} + HPM_{i,t-1} + B_{i,t-1} + B^{lr}_{i,t-1} + IBA^{on}_{i,t-1} + IBA^{term}_{i,t-1} + R^{d}_{i,t-1} \tag{46}$$

$$LM_{i,t} = D_{i,t-1} + IBL^{on}_{i,t-1} + IBL^{term}_{i,t-1} + R^{l}_{i,t-1} + NPL_{i,t-1} + A_{i,t-1} \tag{47}$$

$$b_{i,t} = \begin{cases} \frac{\bar{m}_1 IBA^{on}_{i,t-1} + \bar{m}_2 (L_{i,t-1} + Bb_{i,t-1} + IBA^{term}_{i,t-1}) + \bar{m}_3 B^{lr}_{i,t-1}}{AM_{i,t}} & \text{if } i = \text{commercial} \\ \frac{\bar{m}_1 (L_{i,t-1} + IBA^{on}_{i,t-1}) + \bar{m}_2 (Bb_{i,t-1} + IBA^{term}_{i,t-1}) + \bar{m}_3 B^{lr}_{i,t-1}}{AM_{i,t}} & \text{otherwise} \end{cases} \tag{48}$$

$$a_{i,t} = \frac{\bar{m}_4 D_{i,t-1} + \bar{m}_5 IBL^{term}_{i,-1}}{LM_{i,t}} \tag{49}$$

In the logic of this model, when the condition at Eq. (a) is (not) satisfied, banks have a high (low) margin of stability and ask for overnight (term) funds on the interbank market, implying more (less) frequent market entries for funding purposes. Target financial ratios are thus endogenous and must respect two conditions. As long as the target is not met, banks' demand for overnight funds must differ from zero. Conversely, banks' overnight requests must be null when the target is met.

To do so, banks demand in the overnight segment a *proportion* of the total amount of reserves needed (Eq. (50)).

$$DF^{on}_{i,t} = DF_{i,t}(\theta_t \cdot \Pi^b_{i,t}) \tag{50}$$

Overnight demand depends on two factors. First, a *money market conditions parameter* θ_t that embodies banks' willingness to borrow overnight, dependent on interest rates profitability and the degree of perceived uncertainty (Eq. (51)).

$$\theta_t = \bar{a}_0 + (\overline{icb}^{l} - i^{on}_{t-1}) + (i^{term}_{t-1} - i^{on}_{t-1}) - \overline{PDU}; \text{ with } \bar{a}_0 \sim U(0,1) \tag{51}$$

Second, a *bank-specific parameter*, $\Pi^b_{i,t} \in [0,1]$, which represents banks' *preferences for maturity* and incorporates the target ratios for overnight funds. This parameter computes the difference between the actual overnight borrowing ratio ($BOR_{i,t}$) and the targeted overnight borrowing ratios ($BOR^T_{i,t}$). The actual ratio is the proportion of "unstable" funding sources derived from the NSFR (Eq. (53)). The target ratio is defined such that when banks have a very low degree of stability – when the regulatory margin of stability is not satisfied – their demand for overnight interbank is zero (Eq. (54)). Otherwise, banks can afford overnight contracts since they satisfy the regulatory requirement, and their target ratio equals a random number UN^b picked from the standard uniform distribution – $UN^b_t \sim U(0, BOR_{i,t})$ – which guarantees a positive overnight interbank demand.[13]

$$\Pi^b_{i,t} = BOR_{i,t} - BOR^T_{i,t} \tag{52}$$

$$BOR_{i,t} = 1 - a_{i,t} \tag{53}$$

$$BOR^T_{i,t} = \begin{cases} BOR_{i,t} & if \quad MS_{i,t} < 1 \\ UN^b_t & if \quad MS_{i,t} \geq 1 \end{cases} \tag{54}$$

When stability issues prevent banks from borrowing overnight, a null $\Pi^b_{i,t}$ ensures that the willingness to borrow overnight based on money market rates (θ_t) does not play any role. Banks' access to the term segment of the theorized interbank market is residual (Eq. (55)).

$$DF^{term}_{i,t} = DF_{i,t} - DF^{on}_{i,t} \tag{55}$$

[11] Liabilities are categorized according to their degree of stability, linked to their residual maturity, such that the higher the maturity, the higher the grade of stability, the higher the weight. Instead, assets are classified following their degree of liquidity such that the higher the maturity, the less the liquidity of the item, and the higher the weight.

[12] The maturity weights follow the NSFR prescriptions; see Table 3.

[13] To account for the possibility that banks near this threshold take a mixed portfolio, we evaluate the consistency of our binary choice hypothesis by assuming that the MS threshold is incremented by a small number $\epsilon = \{0.01, 0.05, 0.09\}$. Table D.1 in Appendix D reports the results of this analysis and shows that the volumes exchanged in both segments remain unchanged despite this modification.

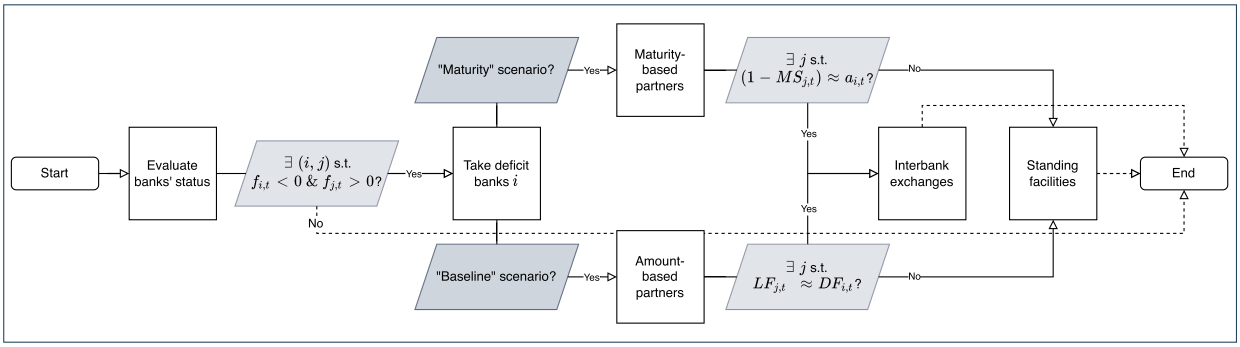

Fig. 3. Interbank matching protocols.

The formalization of the supply side is symmetrical. Overnight supply depends on the willingness to lend overnight and overnight lending ratios (Eq. (56)).

$$LF^{on}_{i,t} = LF_{i,t}(L_b W_t \cdot \Pi^l_{i,t}) \tag{56}$$

The market parameter (Eq. (57)) depends on (i) the opportunity costs of providing funds on the overnight segment rather than on the term one and (ii) the stress perceived on the interbank market PDU.

$$L_b W_t = \bar{a}_0 + \overline{PDU} + (i^{on}_{t-1} - \overline{icb}^d) - (i^{term}_{t-1} - i^{on}_{t-1});\ \text{with } \bar{a}_0 \sim U(0,1) \tag{57}$$

Lending banks' preferences for maturity are captured by the difference between the actual overnight lending ratio ($LOR_{i,t}$) and the targeted overnight lending ratio ($LOR^T_{i,t}$). The actual overnight lending ratio consists of the proportion of short-term assets that should not be backed by stable liabilities. About targeted ratios, the reasoning is symmetric to the demand side. A high degree of stability requires that either the amount of long-term liabilities must increase (numerator) or that the volume of long-term assets must decrease (denominator). When the degree of stability is low (high), long-term assets must decrease (increase): i.e., banks should lend more (less) overnight funds to align the expiration dates of assets and liabilities. Lending banks' supply in the term interbank segment is formalized residually (Eq. (61)). In this case, UN^l_t is bounded between zero and $LOR_{i,t}$.

$$\Pi^l_{i,t} = LOR_{i,t} - LOR^T_{i,t} \tag{58}$$

$$LOR_{i,t} = 1 - b_{i,t} \tag{59}$$

$$LOR^T_{i,t} = \begin{cases} LOR_{i,t} & if \quad MS_{i,t} \geq 1 \\ UN^l_t & if \quad MS_{i,t} < 1 \end{cases} \tag{60}$$

$$LF^{term}_{i,t} = LF_{i,t} - LF^{on}_{i,t} \tag{61}$$

In the "Maturity" scenario, all the exchanges in the two segments of the interbank market thus depend on the values of (i) the market conditions parameters (θ_t and $L_b W_t$), and of (ii) the bank-specific parameters for maturities ($\Pi^b_{i,t}$ and $\Pi^l_{i,t}$). Moreover, since lending banks might not accommodate borrowers' demand for funds, final interbank stocks reflect the *short-side* of the market (Eq. (62)-(63)). For any matching pairs of banks i and j, such that i is a lender and j is a borrower and $\text{link}_{i,j} \neq 0$, interbank assets and liabilities are defined as follows.

$$IBA^{on}_{i,t} = IBL^{on}_{j,t} = \begin{cases} LF^{on}_{i,t} & \text{if} \quad DF^{on}_{j,t} > LF^{on}_{i,t} \\ DF^{on}_{j,t} & \text{if} \quad DF^{on}_{j,t} < LF^{on}_{i,t} \end{cases} \tag{62}$$

$$IBA^{term}_{i,t} = IBL^{term}_{j,t} \begin{cases} LF^{term}_{i,t} & \text{if} \quad DF^{term}_{j,t} > LF^{term}_{i,t} \\ DF^{term}_{j,t} & \text{if} \quad DF^{term}_{j,t} < LF^{term}_{i,t} \end{cases} \tag{63}$$

Banks can access the central bank's standing facilities when interbank matching does not occur, whether it is amount- or maturity-based. While unmatched lending banks deposit their total loanable funds, matchless borrowers demand loans to the central bank for the full amount demanded in the interbank market; see equations (64)-(65).

$$R^l_{i,t} = \begin{cases} DF_{i,t} & \text{if } \{j \mid j \in N_b \text{ and } f_{j,t} > 0\} = \emptyset \text{ or } \text{link}_{i,j} = 0\ \forall j \in N_b \text{ s.t. } f_{j,t} > 0 \\ 0 & \text{otherwise} \end{cases} \tag{64}$$

$$R^d_{i,t} = \begin{cases} LF_{i,t} & \text{if } \{j \mid j \in N_b \text{ and } f_{j,t} < 0\} = \emptyset \text{ or } \text{link}_{i,j} = 0\ \forall j \in N_b \text{ s.t. } f_{j,t} < 0 \\ 0 & \text{otherwise} \end{cases} \tag{65}$$

Fig. 3 summarizes the interbank matching protocols implemented.

Interbank rates and funding costs Interbank interest rates adjust to disequilibrium dynamics in the overnight and term segments, i.e., excess supply or excess demand ϵ_t^{on} and ϵ_t^{term} (Reissl, 2018; Reale, 2022).[14] As such, the two rates must fall within the central bank's corridor. Given that the corridor poses upper and lower bounds limits on interbank rates, a price-clearing mechanism is not feasible. For this reason, the interbank market clears through standing facilities, such that the amount of supply (demand) that cannot be lent on the two interbank segments is deposited (received) at (from) the central bank. The successful clearing of the two segments of the interbank market can be found in Appendix E (see Figs. E.1,E.2).

$$i_t^{on} = \overline{icb}^d + \frac{\overline{icb}^l - \overline{icb}^d}{1 + e^{-(\bar{\sigma}_{ib}\epsilon_t^{on})}} \tag{66}$$

$$\epsilon_t^{on} = \sum_j DF_{j,t}^{on} - \sum_i LF_{i,t}^{on} \tag{67}$$

$$i_t^{term} = \overline{icb}^d + \frac{\overline{icb}^l - \overline{icb}^d}{1 + e^{-(\bar{\sigma}_{ib}\epsilon_t^{term})}} \tag{68}$$

$$\epsilon_t^{term} = \sum_j DF_{j,t}^{term} - \sum_i LF_{i,t}^{term} \tag{69}$$

Banks' funding costs (Eq. (70)) are computed as the average between (i) the exogenous rate the central bank charges on required reserves ($i\bar{c}b^t$), (ii) the interest rates borne on the interbank market, if exchanges occur, and (iii) the lending rate of the central bank's corridor if banks use the corresponding standing facility.[15] Please note that the denominator x changes according to which trades actually occur at each simulation step.

$$\zeta_{i,t} = \frac{\overline{icb}^t + i_t^{on} + i_t^{term} + \overline{icb}^l}{x} \tag{70}$$

Banks update credit market rates according to a mark-up/mark-down rule on previous period funding costs (Eq. (71)-(72)).

$$i_{i,t}^l = \zeta_{i,t-1} + \chi_1 \tag{71}$$

$$i_{i,t}^d = \zeta_{i,t-1} - \chi_1 \tag{72}$$

4. Results

4.1. Simulations

To calibrate the model, we use the parametrization in Table B.1 in Appendix B, which also includes the description of how we derive the initial steady-state values of the aggregate model.[16] We run the model for 100 parallel replicates[17] over 1200 steps and implement two scenarios depending on the interbank matching mechanism.[18] In the "Baseline" scenario, banks are matched according to the total amounts requested and offered, demand and supply in the overnight segment only depend on money market parameters θ and L_bW, and no interbank rationing can occur as lenders accommodate their customer's requests for funds and maturity. When the "Maturity" scenario is active, banks' interbank matching mechanism depends on stability concerns – lenders' maturity mismatch $(1 - MS_{i,t})$ and borrowers' ASF (a_m) – derived from the NSFR construction explained in the previous section. The analysis conducted with this model aims to explore the implications of limiting exposures to maturity mismatches and rollover risk on the clearing operations of the interbank market and also investigates the conditions under which mismatched maturity preferences between surplus and deficit banks affect the functioning of the interbank market and interest-rate steering policies of central banks.[19] To this aim, we perform three main policy experiments in both scenarios: (i) *corridor-shock*, increasing the central bank's interest rates by 50 basis points every 300 steps, (ii) *width-shock*, increasing the ceiling rate by 50 basis points every 300 periods while keeping constant the floor rate, and (iii) *uncertainty-shock*, gradually increasing the level of perceived uncertainty PDU impacting the money market parameters θ and L_bW. Table 2 reports the policy experiments, the shocked variables, and the step ranges at which the shocks occur. For the sake of comparability, we plot the time series relative to the baseline setting where no experiment is

[14] These two measures are positive in case of excess demand and negative in case of excess supply.

[15] The central bank's policy rates, the deposit ($\overline{icb}^d$), and the lending rates ($\overline{icb}^l$) are exogenous and the corridor is assumed to be symmetric such that the targeted interest rate is defined as the average between the two, i.e. $\overline{icb}^t = (\overline{icb}^l + \overline{icb}^d)/2$.

[16] The model simulations are run on Julia, and the code supporting this study's findings is openly available here.

[17] Appendix F reports the results after having run the model also for 25, 50 and 75 runs (see Table F.1).

[18] Stock-flow consistency checks are performed at the end of each simulation period.

[19] We refrain from separating a market efficiency analysis and a monetary policy analysis given the strong emphasis on the functioning of a payment system. Indeed, smooth payment settlements must be ensured either through interbank matching or with the support of the central bank, making the two analyses closely interconnected. Also, we incorporate the central bank's adjustment of policy rates along with its role as a lender of last resort. This approach may bear similarities to a full allotment strategy, such as the one adopted in reaction to the global financial crisis. However, our aim is not to mimic unconventional monetary policies but merely to ensure the effective functioning of the theorized payment system. In other words, our fully accommodative central bank is just emulating a national central bank.

Table 2
Policy experiments and shocks implemented.

Policy experiments	Shocked variables	Step range
Missing-shock	–	–
Corridor-shock	$\overline{icb}^{l} \overset{+}{=} 50$ bp $\overline{icb}^{d} \overset{+}{=} 50$ bp	$[300, 1200] \cap 300\mathbb{Z}$
Width-shock	$\overline{icb}^{l} \overset{+}{=} 50$ bp	$[300, 1200] \cap 300\mathbb{Z}$
Uncertainty-shock	$PDU \overset{+}{=} 0.2$	$[300, 1200] \cap 300\mathbb{Z}$

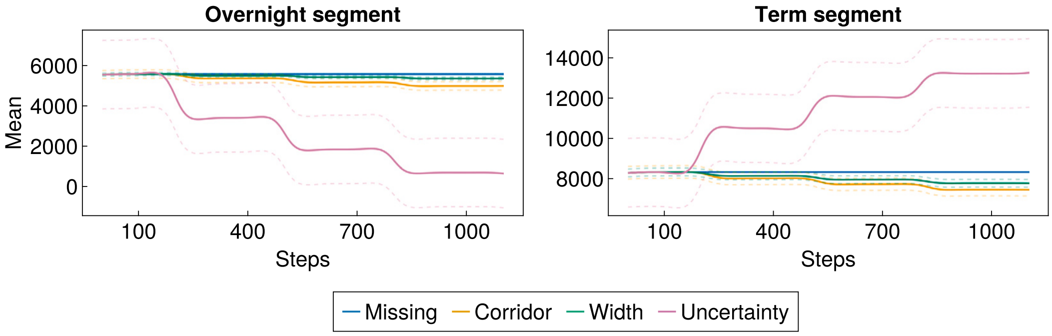

Fig. 4. Dynamics of the interbank market under the Baseline scenario for the overnight (left) and term (right) segments. Four different shocks are compared: Missing (blue), Corridor (orange), Width (green), and Uncertainty (pink). Dashed lines represent the standard deviations.

conducted, i.e., *missing-shock*. We report the results per each scenario and experiment – ruling out the first 100 steps – after having *de-trended* the time series through the Hodrick-Prescott filter for monthly data.

4.2. Policy experiments

4.2.1. Baseline scenario

Fig. 4 depicts the dynamics of the interbank market for the "Baseline" scenario and each shock implemented in levels. The "Missing-shock" time series (blue lines) serves as a benchmark to analyze the results of the experiments. Independently of the shock implemented, banks exchange more funds in the term interbank segment. However, the discrepancy between term and overnight funds is negligible when no shock occurs. An uncertainty shock exerts the highest impact on interbank dynamics: the higher the amount of perceived uncertainty, the greater the tendency of the overnight market to freeze. Indeed, when uncertainty reaches its highest peak (0.8) at the end of the simulation period, almost all funds are exchanged in the term interbank segment, whereas overnight funds tend to zero. Rising uncertainty makes overnight funds decline by more than 80%, ultimately leading to a frozen overnight segment where the demand for overnight funds is almost null. Since margins of stability are inactive and lenders are fully accommodating in this baseline setting, what matters most is the maturity at which deficit banks will be willing to borrow. Thus, this dynamic can be explained by PDU negatively impacting borrowers' money market parameter θ. This demand-led overnight freeze might not be harmful as long as the central bank has the ability to steer interbank rates through conventional monetary policies.[20]

Increasing policy rates – whether in the corridor or width shock – leads to a slightly lower recourse to the two interbank segments. Indeed, increasing corridor rates weaken consumption expenditures and wage payments, reducing the amount of payment flows borne by banks and affecting the recourse to payment settlements (see Fig. C.2). An uncertainty shock, instead, does not pass through the real sector – as payment flows are unaltered – and only negatively impacts overnight exchanges. As such, without a well-functioning term interbank segment, banks' payments smoothing function would be compromised as uncertainty rises, even if supply interbank agents are fully accommodating and do not account for stability concerns.

4.2.2. Maturity scenario

The "Maturity" scenario results are depicted in Fig. 5. Interbank trades mainly occur in the term interbank market, with a large volume discrepancy between the two segments. The term segment is thus crucial to assess whether – and under which conditions – the whole money market may come to a standstill. When maturity and stability issues drive banks' decision-making, the volumes exchanged in the overnight and term segments are respectively 96% and 75% lower than in the "Baseline" scenario (Fig. 4). In other words, banks' rollover concerns may certainly lead the interbank market to freeze. Banks' usage of the central bank's facilities is quite high as the maturity-based interbank matching protocol compromises money market trades by making it more difficult for deficit

[20] Appendix C reports the evolution of interbank interest rates per each shock implemented. As we see from Fig. C.1, the Baseline scenario allows the central bank to anchor interbank rates to its target, whatever the shock, since lending banks are always accommodating and no disequilibrium dynamics occur.

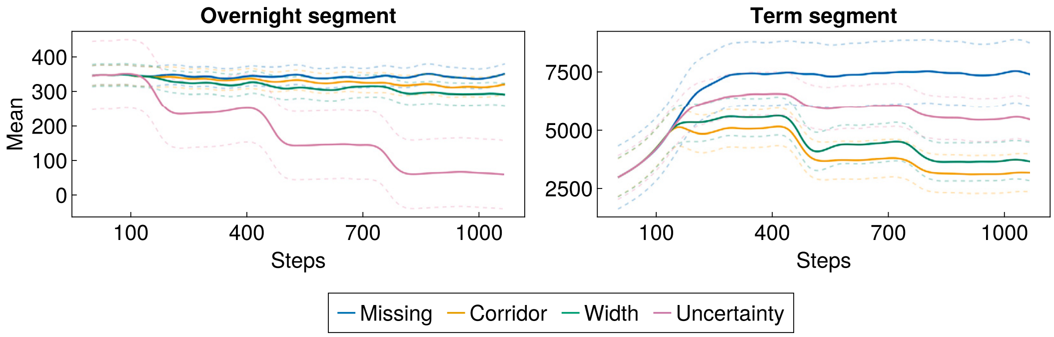

Fig. 5. Dynamics of the interbank market under the Maturity scenario for the overnight (left) and term (right) segments. Four different shocks are compared: Missing (blue), Corridor (orange), Width (green), and Uncertainty (pink). Dashed lines represent the standard deviations.

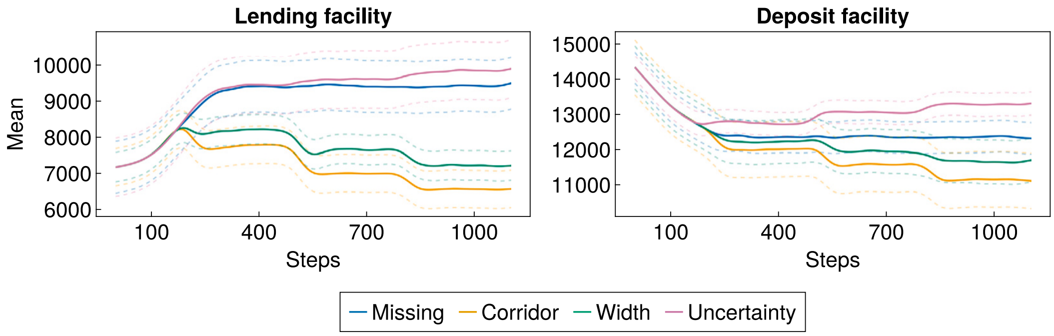

Fig. 6. Recourse to the central bank's lending (left) and deposit (right) facilities under the Maturity scenario. Four different shocks are compared: Missing (blue), Corridor (orange), Width (green), and Uncertainty (pink). Dashed lines represent the standard deviations.

banks to find a suitable partner (see Fig. 6). When uncertainty increases (pink line), the overnight segment tends to freeze even if Π^l and Π^b mediate the impact of money market parameters on short-term interbank demand and supply. Unlike the "Baseline" setting, rising PDU negatively affects term trades despite these now decreasing at lower rates than the ones exchanged in the overnight segment. This dynamic suggests the absence of a substitution effect between the two segments when the "Maturity" scenario is active. Indeed, borrowers' demand for term funds exhibits an increasing pattern (see Fig. C.3), which is, however, not accommodated by surplus institutions. The misalignment between maturity-based preferences is thus responsible for declining volumes in the interbank market as uncertainty grows. The impact of PDU on banks' margin of stability (see Fig. 7) is negligible, and the stability of the overall banking sector seems to satisfy the requirements of the NSFR. However, the evolution of $MS_{i,t}$ diversified by interbank status (Fig. 8) suggests that deficit (surplus) banks experience an overall high (low) degree of stability. This dynamic is not surprising as the higher amount of term liabilities makes borrowers' ASF increase (the numerator of NSFR). Conversely, surplus banks' long-term assets make b_m rise (the denominator of NSFR), discouraging stability. Nevertheless, this result suggests a dual stability-based configuration in the banking sector, resembling the segmented European interbank structure. Indeed, stability divergences between surplus and deficit banks become relevant within a fragmented monetary union, like the European one, characterized by a clear distinction between reserve-scarce peripheral banks and surplus-oriented core banks. During the European interbank fragmentation, deficit banks in the periphery of the Euro Area faced higher funding costs to borrow in the interbank market, discouraging credit provision (Al-Eyd and Berkmen, 2013). This dynamic clearly emerges in this theorized framework: Fig. 9 shows that loans granted by deficit banks are constantly lower in volume than those provided by surplus banks.

Moreover, European core surplus banks' refusal to accommodate interbank borrowers' requests triggered asymmetric funding barriers and led to a halt of overnight exchanges, compromising the central bank's actions (Tropeano, 2019) and revealing country-specific funding barriers (Bonatti et al., 2021) which are incompatible with the conduct of a monetary union (Lapavitsas et al., 2010; Mayordomo et al., 2015). Despite T2 *imbalances accumulation* being outside this model's scope – as we model symmetric payment flows happening within the same country – the "Maturity" scenario tends to replicate some interesting dynamics of the recent interbank fragmentation that led to a massive recourse to the standing facilities and forced the European central bank to intervene with unconventional measures. As such, the asymmetric funding frictions behind the interbank fragmentation could also be induced by mismatched preferences for maturities and the unbalanced distribution of rollover risks within the banking sector. While these considerations point to an additional rollover-based source of interbank segmentation that goes beyond the usual sovereign- (Cesaratto, 2013; De Santis, 2019) and credit-risk (Eisenschmidt et al., 2018) dichotomy, we leave the interaction between different types of risks and a multi-country analysis for future research. However, these results are in line with Bechtel et al. (2022)'s empirical findings who emphasize that (i) immediate settlements of real-sector transactions exacerbate banks' liquidity management and can

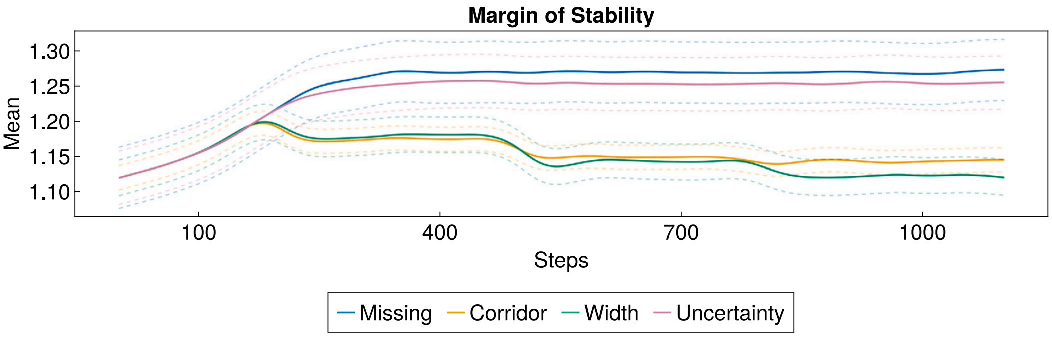

Fig. 7. Banks' margin of stability under the Maturity scenario. Four different shocks are compared: Missing (blue), Corridor (orange), Width (green), and Uncertainty (pink). Dashed lines represent the standard deviations.

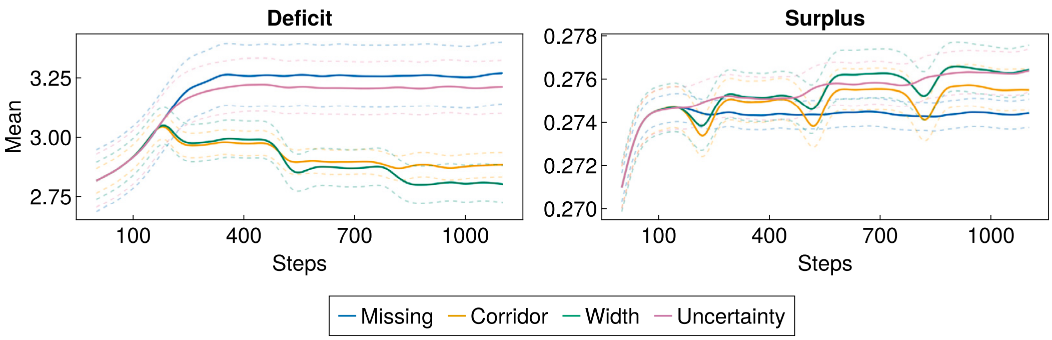

Fig. 8. Average margin of stability under the Maturity scenario for deficit (left) and surplus (right) banks. Four different shocks are compared: Missing (blue), Corridor (orange), Width (green), and Uncertainty (pink). Dashed lines represent the standard deviations.

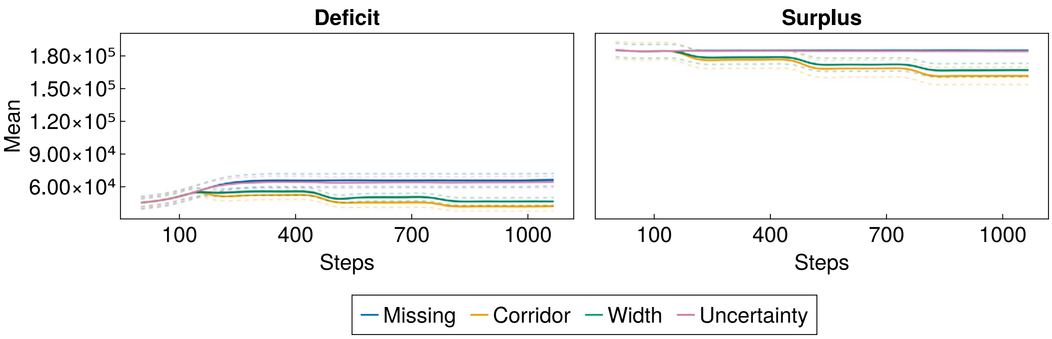

Fig. 9. Real sector loans under the Maturity scenario for deficit (left) and surplus (right) banks. Four different shocks are compared: Missing (blue), Corridor (orange), Width (green), and Uncertainty (pink). Dashed lines represent the standard deviations.

be an additional source of financial instability, and (ii) that rollover-based risks triggering banks' heterogeneous funding costs may also persist in periods of *financial quietness*, i.e., when the banking sector's stability is not jeopardized.

Increasing corridor rates (orange and green lines) reduce average stability. However, the banking system seems resilient over the long-run as MS does not fall below 1. However, the impact of policy rate shocks on banks' stability margins is asymmetric. When we look at deficit vs. surplus banks (Fig. 8), higher rates weaken deficit banks' $MS_{i,t}$ more than they strengthen lenders' stability conditions. It is therefore important to pay special attention to deficit banks, whose decreasing stability could ultimately lead to unsatisfied NSFRs and further frictions on the interbank market due to lenders' refusal to meet their customers' maturity requests. Maturity-based issues become relevant in this scenario as the central bank can not steer interbank interest rates toward the desired target through conventional monetary policies, see Fig. 10. Divergent maturity preferences between lenders and borrowers in the money market thus lead to disequilibrium dynamics that make the overnight rate (term rate) to be anchored to the policy floor (ceiling) due to a constant excess supply (demand) condition.

The "Maturity" scenario is characterized by non-accommodating lenders who can ration their clients due to maturity preferences. Interbank rationing thus endogenously emerges from agents' interactions and the evolution of surplus and deficit banks' degree of stability. Fig. 11 depicts the evolution of a rationing measure (Γ) for the overnight and term segments. Γ has been constructed such

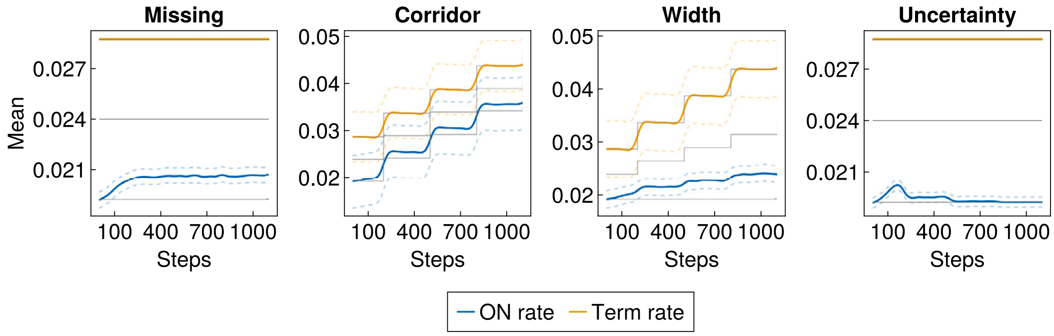

Fig. 10. Dynamics of interbank rates under the Maturity scenario for the overnight (blue) and term (orange) segments across the four shocks considered: Missing (left), Corridor (central left), Width (central right), and Uncertainty (right). Dashed lines represent the standard deviations.

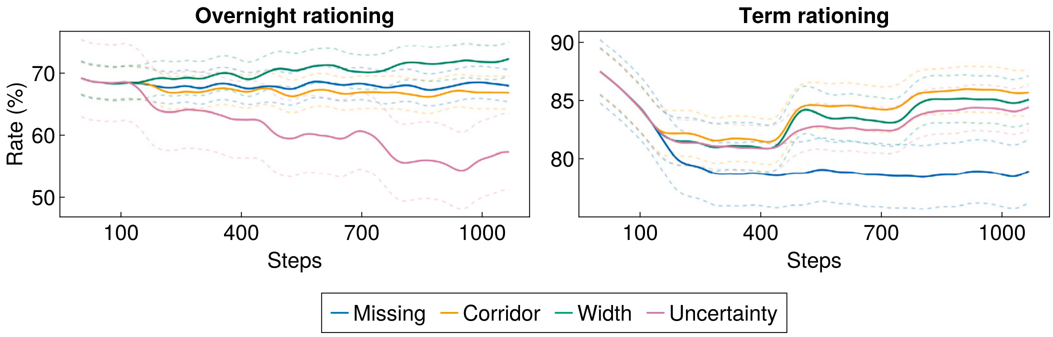

Fig. 11. Interbank rationing ($\Gamma^x = (1 - \frac{IBL^x}{DF^x}) \in [0,1]$, for any generic sub-market $x = \{\text{ON}, \text{Term}\}$) under the Maturity scenario for the overnight (left) and term (right) segments. Four different shocks are compared: Missing (blue), Corridor (orange), Width (green), and Uncertainty (pink). Dashed lines represent the standard deviations.

Table 3
Implicit contractual maturities and weights; m stands for months and y for years.

	Parameter	Variable	Maturity	NSFR-value	Tests range
Assets	m_1	Lf, IBA^{on}	$M < 6m$	0.1	$[0,1] \cap 0.1\mathbb{Z}$
	m_2	Bb, Lh, IBA^{term}	$6m \leq M \leq 1y$	0.5	$[0,1] \cap 0.1\mathbb{Z}$
	m_3	B^{lr}	$M \geq 1y$	0.05	$[0,1] \cap 0.1\mathbb{Z}$
Liabilities	m_4	Dh, Df		0.9	$[0,1] \cap 0.1\mathbb{Z}$
	m_5	IBL^{term}	$6m \leq M \leq 1y$	0.5	$[0,1] \cap 0.1\mathbb{Z}$

that rationing is null when the amount of liabilities for a certain market (IBL^x) equals demand (DF^x): $\Gamma^x = (1 - \frac{IBL^x}{DF^x}) \in [0,1]$, for any generic sub-market $x = \{\text{ON}, \text{Term}\}$. In the absence of shocks (blue line), roughly 68% of overnight customers are rationed, compared to the 80% in the term segment. The shocks impact the overnight segment asymmetrically: while uncertainty and increasing corridor rates reduce the amount of unsatisfied customers, width-based shocks exert the opposite effect. Despite a decreasing demand (Fig. C.3) should lead rationing to shrink, policy rate shocks trigger a higher proportion of rationed interbank customers. In this case, final interbank liabilities in the corridor- and width-shocks seem to follow decreasing lenders' supplies driven by Π^l, making both IBL and DF decrease. Term rationing almost reaches 90% under a corridor shock since term trades are highly discouraged by synchronized increases in policy rates. Therefore, (i) a corridor-based contractionary shock (orange line) combined with surplus banks highly exposed to rollover risks may result in severe frictions in the term segment, while (ii) a width-based shock (green line) may fully compromise the efficient functioning of the overnight unsecured interbank market.

4.3. Sensitivity analysis

We perform sensitivity tests to check how altering the weights of the NSFR impacts the steady-state dynamics of the "Maturity" scenario (missing shock). To do so, we alter the parameters characterizing the computation of a_m and b_m (Eq. (49) - (48)) from 0 to 1 incremented by 0.1. Table 3 summarizes the parameters under investigation, the corresponding variables, and the theoretical maturity assigned following the NSFR (Basel Committee on Banking Supervision, 2014). The table reporting the analysis for m_2, m_3 and m_5 are in Appendix D, as no significant alteration to the baseline trend occurs. Each test is conducted by altering one parameter at a time, all else being equal.

Table 4
Results for the sensitivity analysis on NSFR-based parameters m_1 and m_4, impacting respectively short-term assets and deposits. The table reports how overnight and term volumes respond to changes in the above-mentioned parameters when the value ranges from zero to one. The bold values refer to the baseline assignment in the main simulations of the model.

	m_1		m_4	
Range	ON volumes	Term volumes	ON volumes	Term volumes
0.0	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
0.1	**374.4628** **(34.2263)**	**6176.5824** **(1517.2239)**	0.0 (0.0)	0.0 (0.0)
0.2	358.0437 (31.6718)	6140.2908 (1508.2232)	0.0 (0.0)	0.0 (0.0)
0.3	603.3368 (1507.4294)	4111.7879 (4823.3449)	0.0 (0.0)	0.0 (0.0)
0.4	126.2073 (88.3703)	1997.6754 (1741.9015)	72.6228 (47.6179)	349.5694 (158.9483)
0.5	127.7253 (223.2296)	1426.2341 (1407.2593)	69.6033 (18.9201)	320.2984 (175.6845)
0.6	61.3771 (56.3408)	1025.4723 (787.6698)	164.7373 (47.4379)	991.7144 (277.1732)
0.7	50.613 (42.9545)	786.6198 (533.081)	372.3721 (380.6487)	2836.9287 (2844.7164)
0.8	31.6535 (5.8407)	587.0324 (153.6387)	437.0221 (36.7553)	6111.9598 (1489.8267)
0.9	26.5052 (6.0442)	582.4558 (182.3969)	**374.4628** **(34.2263)**	**6176.5824** **(1517.2239)**
1.0	23.9549 (7.5003)	554.8176 (127.5553)	0.0 (0.0)	0.0 (0.0)

Table 4 report the results of the analysis conducted on m_1, which impacts the RSF factor of short-term firms' loans and overnight interbank volumes, and m_4, i.e. the ASF factor of deposits. Looking at the volumes exchanged in the interbank market when m_1 changes, all parameter values outside the range $[0.1, 0.2]$ lead to almost a full freeze of both segments. Indeed, a high weight assigned to short-term loans strongly alters the ability of reserve-scarce banks to find lenders in the interbank market, making the banking sector more exposed to the central bank's standing facilities. When m_1 is 0.2, term (overnight) trades are slightly higher (lower). This symmetric effect arises because a slight increase in m_1 induces b_m to rise – the denominator of the NSFR – hindering banks' stability. Consequently, banks look for more stable portfolio configurations and are more prone to hold term assets and liabilities. However, further increases in this short-term RSF factor may have negative effects on the whole system, as frozen interbank activities compromise the functioning of the payment system and the theorized economy as a whole. This dynamic could be interpreted as a sign of increasing holdings of illiquid assets that could not be easily rolled over or sold at fire sales prices.

A slight decrease of the weight assigned to households' and firms' deposits (m_4) from 0.9 (baseline) to 0.8 boosts interbank volumes while leaving unaffected the higher reliance on term exchanges. This low decrease in m_4 should, however, discourage overnight loans as a higher ASF risk factor reduces banks' margins of stability. This dynamic does not emerge because stability margins are overall satisfied for values of m_4 closer to the baseline setting. Instead, as the parameter is lower than 0.7, the stability of the banking sector as a whole is strongly compromised, leading to a halt of bilateral interbank trades. Indeed, a lower m_4 implies that term deposits lose stability as the propensity of customers to withdraw their funding increases, jeopardizing financial stability.

Alterations of short-term loans and deposit weights (m_1 and m_4 respectively) thus exert the highest impact on the model's dynamics. Some parameter values could also lead the whole interbank market to freeze and compromise the maturity-based stability of the banking system. As such, policymakers and research practitioners should not neglect the interaction between the NSFR and rollover-based interbank dynamics. This issue is of greater importance in Europe, where asymmetric funding barriers may also be associated with unbalanced stability conditions and mismatched maturity preferences between peripheral deficit banks and core surplus institutions.

5. Conclusions

This paper enriches the literature on interbank market fragmentation by shifting focus to rollover-induced tensions. To do so, it advances multi-agent analyses by exploring how maturity preferences contribute to funding asymmetries. Our approach also refines existing AB-SFC frameworks, modeling a theoretical payment system where heterogeneous banks exchange reserves in the unsecured interbank market to settle real sector transactions and investigating how rollover-based decisions affect the money market and central bank measures. Two scenarios were modeled: the "Baseline" (banks seek optimal overnight and term funds) and the "Maturity" scenario (banks follow maturity targets under Basel III NSFR). In both scenarios, banks can turn to central bank facilities when needed.

We applied shocks to both scenarios, observing the effects of increased uncertainty and monetary policy changes. In the "Baseline" scenario, increased uncertainty led to a shift from overnight to term trades, while in the "Maturity" scenario, maturity mismatches led to reliance on the central bank and ineffective monetary policy. The study also revealed a stability divergence between surplus and deficit banks, reflecting the European interbank structure. The results suggest rollover-induced interbank fragmentation and asymmetric funding frictions despite overall banking stability. Sensitivity analysis on NSFR weights indicated potential instability in the interbank market due to liquidity and deposit stability changes, highlighting the need for joint analysis of NSFR and rollover dynamics.

The findings of our study offer insights for central banks in managing interbank market tensions, particularly under the influence of rollover-induced frictions and divergent maturity preferences. While central banks routinely adjust their policies to market conditions, our research underlines the need for more targeted and finely-tuned interventions. These could include the development of more sophisticated fragmentation indices, the creation of segment-specific facilities to address rollover stress levels in the market, and strengthened collaboration with regulatory bodies. Such tailored approaches, informed by the dynamics highlighted in our study, could significantly improve central banks' capacity to maintain stability and efficiency in the interbank market, especially during periods characterized by complex rollover dynamics.

This study is a preliminary step in a broader research agenda aimed at extending this framework to a multi-country setting with diverse sectors and institutions, including different interbank segments and collateralization levels. Future research should also explore default mechanisms, non-accommodating lenders, heterogeneous agent behaviors, and interactions between various financial risks.

Data availability

IMS (Original Data) (GitHub)

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Appendix A. SFC structure

Table A.1
Transaction flow matrix.

		Firms			Commercial Banks j		Business Banks k		Central Bank		
	Government	Current	Capital	Households	Current	Capital	Current	Capital	Current	Capital	Σ
Consumption		$+C$		$-C$							0
Government expenditures	$-G$	$+G$									0
Investments		$+I$	$-I$								0
Inventories		$+\Delta INV$	$-\Delta INV$								0
Wages		$-W$		$+W$							0
Taxes	$+T$			$-T$							0
Interests on bills	$-\bar{i}_b B_{t-1}$				$+\bar{i}_b B_{j,t-1}$		$+\bar{i}_b B_{k,t-1}$		$+\bar{i}_b B_{cb,t-1}$		0
Interests on bonds	$-\bar{i}_b^{lr} B_{t-1}^{lr}$				$+\bar{i}_b^{lr} B_{j,t-1}^{lr}$		$+\bar{i}_b^{lr} B_{k,t-1}^{lr}$				0
Interests on loans		$-i_{k,t-1}^{l} L_{f,t-1}$		$-i_{j,t-1}^{l} L_{h,t-1}$	$+i_{j,t-1}^{l} L_{j,t-1}$		$+i_{k,t-1}^{l} L_{k,t-1}$				0
Interests on deposits		$+i_{k,t-1}^{d} Df_{t-1}$		$+i_{j,t-1}^{d} Dh_{t-1}$	$-i_{j,t-1}^{d} D_{j,t-1}$		$-i_{k,t-1}^{d} D_{k,t-1}$				0
Interests on reserves					$+\overline{icb}^{t} HPM_{j,t-1}$		$+\overline{icb}^{t} HPM_{k,t-1}$		$-\overline{icb}^{t} HPM_{t-1}$		0
Interests on advances					$-\overline{icb}^{t} A_{j,t-1}$		$-\overline{icb}^{t} A_{k,t-1}$		$+\overline{icb}^{t} A_{t-1}$		0
Interests on lending facility					$-\bar{i}_{cb}^{l} R_{j,t-1}^{l}$		$-\bar{i}_{cb}^{l} R_{k,t-1}^{l}$		$+\bar{i}_{cb}^{l} R_{t-1}^{l}$		0
Interests on deposit facility					$+\bar{i}_{cb}^{d} R_{j,t-1}^{d}$		$+\bar{i}_{cb}^{d} R_{k,t-1}^{d}$		$-\bar{i}_{cb}^{d} R_{t-1}^{d}$		0
Profits of firms		$-Pf$		$+Pf$							0
Profits of banks				$+Pb_j + Pb_k$	$-Pb_j$		$-Pb_k$				0
Profits of cb	$+Pcb$								$-Pcb$		0
Loan defaults	$-\Delta NPL$					$+\Delta NPL_j$		$+\Delta NPL_k$			0
Δbills	$+\Delta B$					$-\Delta B_j$		$-\Delta B_k$		$-\Delta Bcb$	0
Δbonds	$+\Delta B^{lr}$					$-\Delta B_j^{lr}$		$-\Delta B_k^{lr}$			0
Δloans			$+\Delta L_f$	$+\Delta L_h$		$-\Delta L_j$		$-\Delta L_k$			0
Δdeposits			$-\Delta Df$	$-\Delta Dh$		$+\Delta D_j$		$+\Delta D_k$			0
Δhigh powered money						$-\Delta HPM_j$		$-\Delta HPM_k$		$+\Delta HPM$	0
Δhigh powered money						$+\Delta A_j$		$+\Delta A_k$		$-\Delta A$	0
Δlending facility						$+\Delta R_j^{l}$		$+\Delta R_k^{l}$		$-\Delta R^{l}$	0
Δdeposit facility						$-\Delta R_j^{d}$		$-\Delta R_k^{d}$		$+\Delta R^{d}$	0
Σ	0	0	0	0	0	0		0	0	0	0

Appendix B. Parameters and initial values

The computation of the initial steady state (SS) values of the aggregate version of the system is simplified by the SFC structure of the model. We set the value of capital stock and government spending exogenously based on Eurostat's statistics for gross fixed capital formation and government expenditure on general public services reported in 2022. Moreover, we impose a government debt-to-GDP ratio equal to 0.9 that resembles the data reported for the Euro Area, thanks to which we can compute all the remaining variables of the model. We also run sensitivity tests to check the impact of this assumption on the model dynamics; see Appendix D. The exogenous parameters are described in Table B.1, while Table B.2 summarizes the derived initial values which guarantee the SS dynamics of the baseline settings, i.e., the *missing-shock* simulations for both scenarios implemented. While the variables concerning the interbank market are initialized to 0, NSFR components are computed when the "Maturity" scenario is initialized as reported in Table B.3.

Table B.1
Exogenous parameters.

Symbol	Remark	Description	Value	Sensitivity Analysis	Shock
N_f	pre-SS	Number of firms	100	–	–
N_h	pre-SS	Number of households	1000	–	–
Nb_j	pre-SS	Number of commercial banks	20	–	–
Nb_k	pre-SS	Number of business banks	20	–	–
PDU	pre-SS	Perceived degree of uncertainty	0.1		$\{0.3, 0.5, 0.7, 0.9\}$
r	free	Initial GD/GDP ratio	0.9	$\{0.9, 1.1, 1.3\}$	–
g	emp	Government spending	8750.0	–	–
δ	free	Capital depreciation	0.05	$\{0.05, 0.5, 1.0\}$	–
ϕ	pre-SS	Adaptive expectations parameter	0.25	–	–
β	pre-SS	Linear expectation parameter	0.5	–	–
σ	pre-SS	Inventory target parameter	3	–	–
μ	pre-SS	Reserve requirement	0.25	–	–
υ	pre-SS	Proportion of advances	0.1	–	–
ω	pre-SS	Nominal wages	0.2	–	–
l	free	Share of non-performing loans	0.03	$\{0.03, 0.5, 1.0\}$	–
pr	pre-SS	Labour productivity	1.0	–	–
τ	pre-SS	Taxes on households' wages	0.18	–	–
γ	free	Households' leverage	0.1	$\{0.1, 0.5, 1.0\}$	–
i_b	pre-SS	Interest rate on bills	0.024	–	–
i_b^{lr}	pre-SS	Interest rate on bonds	0.0219	–	–
i_{cb}^t	pre-SS	Central bank target	0.024	–	$\{0.029, 0.034, 0.039, 0.044\}$
i_{cb}^l	pre-SS	Central bank ceiling	0.0287	–	$\{0.0337, 0.0387, 0.0437, 0.04869\}$
i_{cb}^d	pre-SS	Central bank floor	0.01925	–	$\{0.02425, 0.02925, 0.03425, 0.03925\}$
g_k	pre-SS	Desired investments	0.1	–	–
ρ	pre-SS	Markup on prices	0.4	–	–
α_1	lit	Propensity to consume out of income	0.8	–	–
α_2	SS-given	Propensity to consume out of networth	0.0460694	–	–
χ	lit	Number of potential partners	5	–	–
χ_1	pre-SS	Markup/markdown on funding costs	0.0085	–	–
λ	lit	Intensity of choice parameter	2.00687	–	–
g_d	free	Proportion of firms' deposits	0.1	$\{0.1, 0.5, 1.0\}$	–
σ_{ib}	pre-SS	Sensitivity to interbank disequilibrium	0.1	–	

Table B.2
Initial values of the aggregate model.

Symbol	Remark	Description	Value
G	pre-SS	Government spending	2450
T	SS-given	Taxes	4375
B	SS-given	Government bills	109375
Bcb	SS-given	Central bank bills	11041.365
H	SS-given	Required reserves	54589.5833
A	SS-given	Advances	43548.2183
R^d	pre-SS	Deposit facility	0
R^l	pre-SS	Lending facility	0
C	SS-given	Nominal consumption	31492.7138
c	SS-given	Real consumption	112473.98
Yd	SS-given	Disposable income	31492.7134
W	SS-given	Wages	24305.56
Lh	SS-given	Households' loans	16821.127
Dh	SS-given	Households' deposits	153539.6825
NWh	SS-given	Households' net worth	136718.555
p	SS-given	Prices on consumption goods	0.28
UC	SS-given	Unit direct costs	0.2
I	SS-given	Investments	85.064
K	pre-SS	Capital	3038
y	pre-SS	Output	121527.78
INV	SS-given	Nominal inventories	24305.56
inv	SS-given	Real inventories	121527.78
inv^T	SS-given	Inventory target	121527.78
N	SS-given	Labor demand	121527.78
Lf	SS-given	Firms' loans	29774.11
Df	SS-given	Firms' deposits	2430.555
Pf	SS-given	Firms' profits	8762.4631
Bb	SS-given	Banks' bills	9833.635
i^l	SS-given	Interest on loans	0.0335
i^d	SS-given	Interest on deposits	0.0155
Pb	SS-given	Banks' profits	1768.4018
Pcb	pre-SS	Central bank's profits	0

Table B.3
Initialization NSFR components - Maturity scenario.

Symbol	Remark	Description	Value	
			Business	Commercial
LM	SS-given	Total liabilities	30624.80555	168893.65073
AM	SS-given	Total assets	30624.80555	168893.65073
a_m	SS-given	ASF risk factor	0.0714	0.81
b_m	SS-given	RSF risk factor	0.09722	0.34
MS	SS-given	Margin of stability	0.73469	2.4

Appendix C. Additional figures

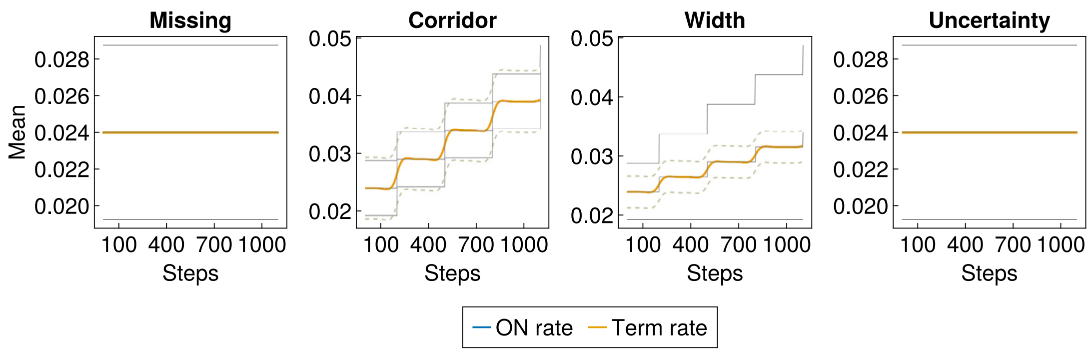

Fig. C.1. Dynamics of interbank rates under the Baseline scenario for the overnight (blue) and term (orange) segments across the four shocks considered: Missing (left), Corridor (central left), Width (central right), and Uncertainty (right). Dashed lines represent the standard deviations.

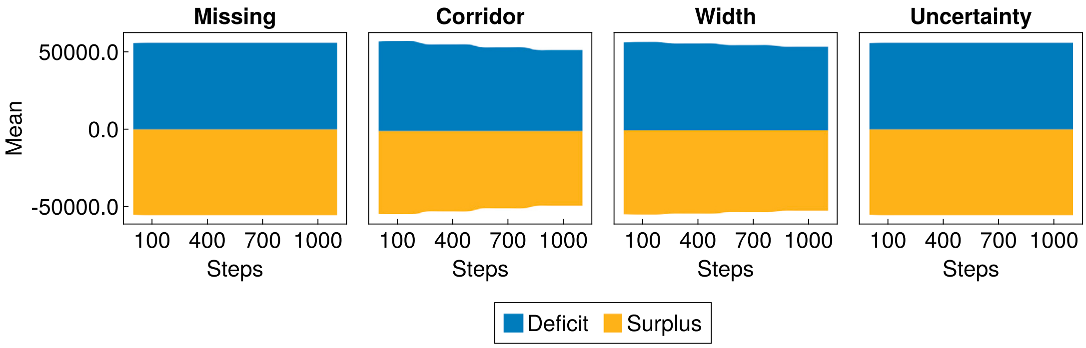

Fig. C.2. Payment flows under the Baseline scenario for the deficit (blue) and surplus (orange) banks across the four shocks considered: Missing (left), Corridor (central left), Width (central right), and Uncertainty (right).

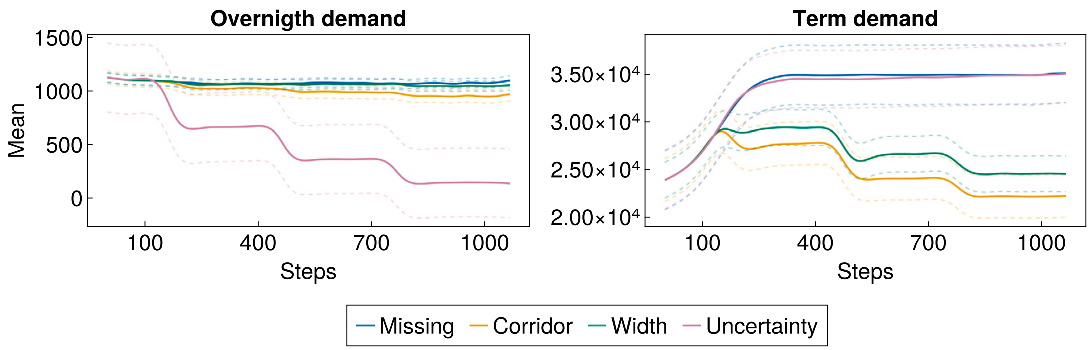

Fig. C.3. Dynamics of interbank demand under the Maturity scenario for the overnight (left) and term (right) segments. Four different shocks are compared: Missing (blue), Corridor (orange), Width (green), and Uncertainty (pink). Dashed lines represent the standard deviations.

Appendix D. Additional sensitivity analyses

We test our binary choice assumption in the two interbank segments considered. We account for banks in the proximity of the margins of stability threshold to still adopt a mixed portfolio of overnight and term maturities. To do so, we simply added an exogenous parameter in Eq. (54) and (60) that increases MS by 0.01, 0.05 and 0.09. Table D.1 reports the results of this analysis and shows that the volumes exchanged in both markets are not altered by this modification.

Table D.1
Sensitivity analysis on the margin of stability's threshold. Values in bold refer to the main simulation results. Numbers in parentheses are standard deviations.

	Volumes	
Range	ON	Term
0.0	**374.4628 (34.2263)**	**6176.5824 (1517.2239)**
0.01	374.4628 (34.2263)	6176.5824 (1517.2239)
0.05	374.4628 (34.2263)	6176.5824 (1517.2239)
0.09	374.5124 (34.2424)	6176.4608 (1517.8047)

The results for the sensitivity analysis on NSFR parameters not included in the main text can be found in Table D.2.

In addition to the sensitivity tests performed on NSFR parameters, we perform robustness checks on our initial assumptions concerning the debt-to-GDP ratio (r), capital depreciation (δ), the share of non-performing loans (l), households' leverage (γ), and firms' propensity for deposits (g_d). We run the analysis for the "Baseline" scenario for several parameter ranges. We report the results for firms' output and the overnight interbank segment in Fig. D.1-D.2. The results show that varying levels of the parameters of interest within the ranges considered do not alter the system's dynamics, as only variable levels are affected.

Table D.2
Results for the sensitivity analysis on NSFR-based parameters m_2, m_3 and m_5, impacting respectively long-term credit, long-term government bonds and term interbank liabilities. The table reports how overnight and term volumes respond to changes in the above-mentioned parameters when the value ranges from zero to one. The bold values refer to the baseline assignment in the main simulations of the model. The baseline value for m_3 is 0.05, which is not included in the range considered. Numbers in parentheses are standard deviations.

	m_2		m_3		m_5	
Range	ON volumes	Term volumes	ON volumes	Term volumes	ON volumes	Term volumes
0.0	373.3437 (34.7523)	7168.8808 (1923.3899)	374.0375 (34.8376)	6564.7756 (1704.7922)	376.4783 (35.0253)	6579.0067 (1713.552)
0.1	374.0937 (35.1828)	7100.9873 (1975.0599)	378.4213 (35.5603)	6382.7298 (1676.9796)	375.4491 (35.0851)	6574.364 (1719.3571)
0.2	1374.2597 (34.0487)	6166.7286 (1515.5966)	373.1034 (35.8053)	6599.4104 (1701.0687)	375.5654 (34.0601)	6149.3215 (1550.937)
0.3	374.3478 (34.0458)	6175.9573 (1510.0203)	371.5816 (33.8451)	6375.3337 (1653.2799)	375.5415 (33.5412)	6145.7957 (1537.9705)
0.4	374.6832 (33.9679)	6175.0709 (1514.1954)	372.598 (32.3106)	6492.3338 (1713.3252)	374.846 (34.1109)	6155.662 (1533.3566)
0.5	**374.4628** **(34.2263)**	**6176.5824** **(1517.2239)**	374.3743 (32.4814)	6683.5263 (1772.5474)	**374.4628** **(34.2263)**	**6176.5824** **(1517.2239)**
0.6	374.0017 (34.2625)	6191.0757 (1522.2781)	370.2611 (32.022)	6475.289 (1646.47)	374.3674 (34.0189)	6139.6414 (1548.1865)
0.7	373.6099 (34.0182)	6189.8088 (1522.7278)	372.2484 (31.2567)	6788.4959 (1839.1662)	373.021 (33.1623)	6189.6177 (1528.2062)
0.8	373.0326 (33.9591)	6190.0085 (1524.9994)	370.3983 (31.3594)	6506.7432 (1639.8351)	371.9514 (33.8997)	6114.4839 (1493.0486)
0.9	372.9833 (33.8407)	6186.66 (1529.459)	369.7126 (31.2393)	6041.9243 (1538.8327)	371.5699 (31.9909)	6121.9381 (1453.6231)
1.0	372.6586 (33.5999)	6193.9694 (1525.5553)	367.8989 (29.6896)	6404.8641 (1623.4338)	370.9981 (33.4094)	6140.4787 (1426.2913)

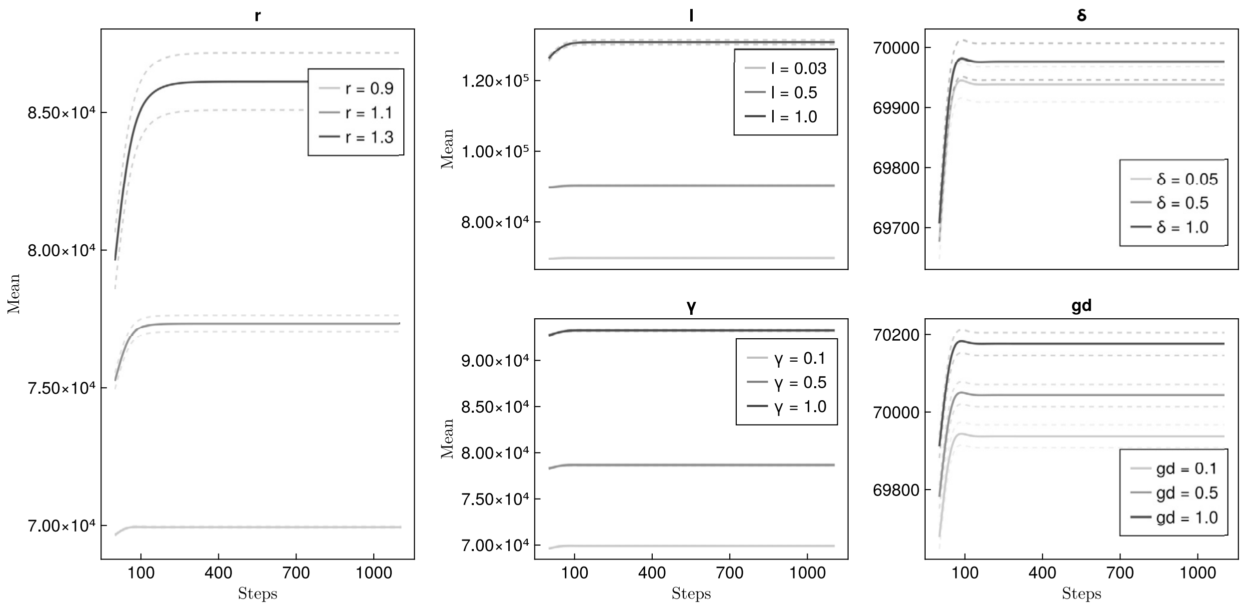

Fig. D.1. GDP dynamics per parameter changes: debt-to-GDP ratio (bigger plot), share of non-performing loans (top left), capital depreciation (top right), households' leverage (bottom left), and firms' propensity for deposits (bottom right). Stronger grey lines correspond to higher parameter values. Dashed lines represent the standard deviations.

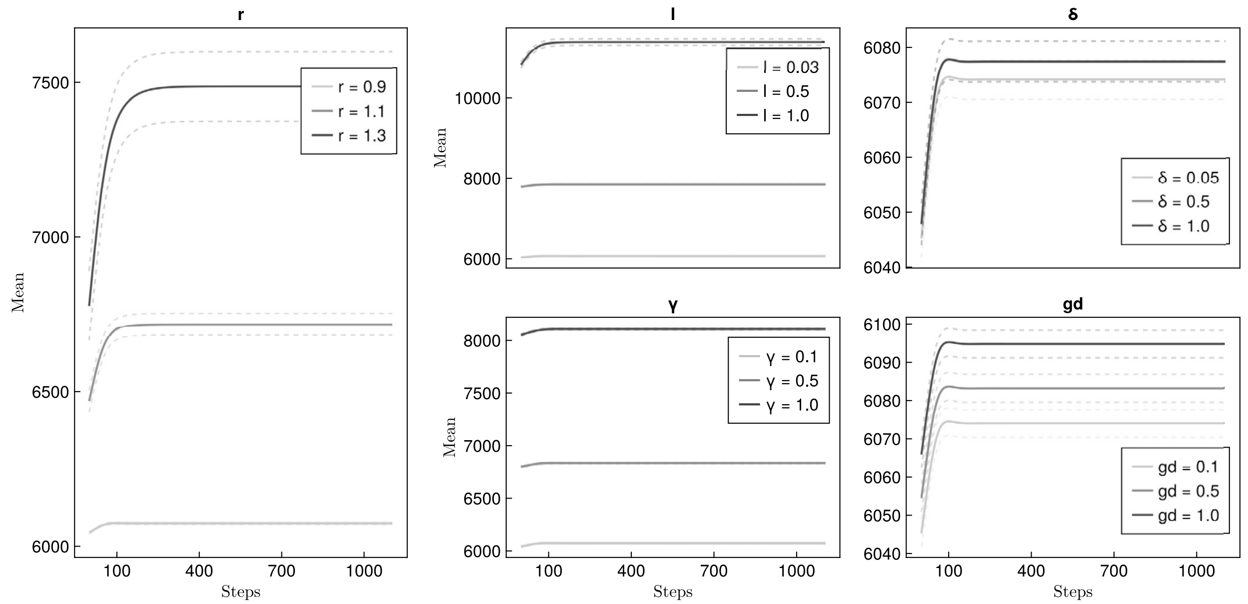

Fig. D.2. Overnight volumes dynamics per parameter changes: debt-to-GDP ratio (bigger plot), share of non-performing loans (top left), capital depreciation (top right), households' leverage (bottom left), and firms' propensity for deposits (bottom right). Stronger grey lines correspond to higher parameter values. Dashed lines represent the standard deviations.

Appendix E. Interbank clearing

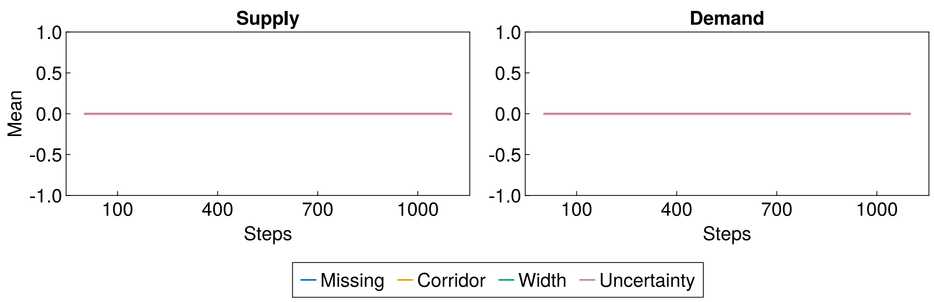

Fig. E.1. Interbank clearing under the Baseline scenario. The time series for the supply side (left) reports the sum interbank assets (IBA^{on} and IBA^{term}) and reserves deposited at the central bank (R^d) minus total supply (LF). The time series for the demand side (right) reports the sum interbank liabilities (IBL^{on} and IBL^{term}) and reserves obtained from the lending facility of the central bank (R^l) minus total demand (DF). Four different shocks are compared: Missing, Corridor, Width, and Uncertainty. Both supply- and demand-side time series are equal to zero because lenders are fully accommodative. The dashed lines represent the standard deviations.

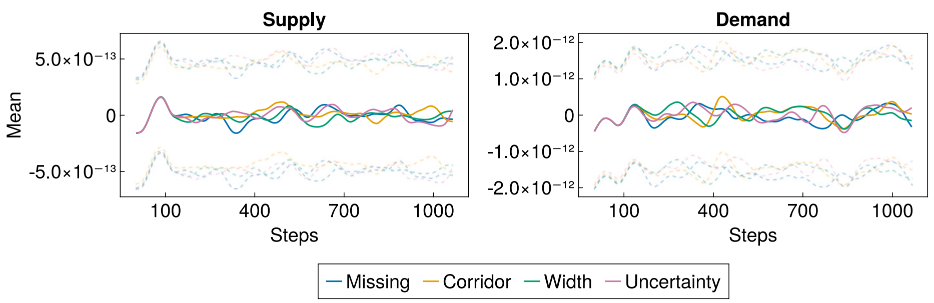

Fig. E.2. Interbank clearing under the Maturity scenario. The time series for the supply side (left) reports the sum interbank assets (IBA^{on} and IBA^{term}) and reserves deposited at the central bank (R^d) minus total supply (LF). The time series for the demand side (right) reports the sum interbank liabilities (IBL^{on} and IBL^{term}) and reserves obtained from the lending facility of the central bank (R^l) minus total demand (DF). Four different shocks are compared: Missing, Corridor, Width, and Uncertainty. In the supply graph (left), all conditions fluctuate around the mean value of zero, while in the demand graph (right), the conditions exhibit a similar pattern with minor deviations from the mean. The dashed lines represent the standard deviations.

Appendix F. Standard error analysis

Table F.1
Mean, standard deviation, and standard error of overnight and term volumes for different numbers of runs - Maturity-scenario.

Variable	Number of Runs	Mean	Standard Deviation	Standard Error
Overnight volumes	25	360.89***	58.8439	11.7687
	50	373.73***	46.9534	6.6402
	75	364.47***	38.9280	4.4950
	100	374.46***	34.2263	3.4226
Term volumes	25	5761.25***	1765.7693	353.1538
	50	5822.54***	1288.54300	182.2274
	75	6559.41***	1805.8707	208.5239
	100	6176.58***	1517.2239	151.7223

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