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Interbank market and funding liquidity risk in a stock-flow consistent model

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Abstract

The present stock-flow consistent model aims at capturing the second causal link of endogenous monetary theory, from deposits to reserves, by including intrasectoral flows within the banking sector and *debt maturity structure* decisions. For this purpose, banks can choose the demanded duration of interbank loans, either overnight or term, according to a measure for maturity mismatch which captures funding liquidity risk. The simulations show that: (i) a well-functioning term interbank market is needed when banks face exogenous shocks; and (ii) banks' funding structure may act as an endogenous source of credit market pressures.

KEYWORDS

interbank market, monetary policy, rollover risk, stock-flow consistent models

JEL CLASSIFICATION

E5; E12; E42; G01; G11; G18; G21; G32

1 | INTRODUCTION

Since the last financial crisis, interbank market dynamics have gathered greater attention among researchers. In the light of what happened after the collapse of Lehman Brothers, impaired

This paper includes an online Appendix in which the author provides additional equations and tables, demonstrations and the sensitivity analysis.

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interbank market transactions have proved to be harmful to the infrastructures of the prevailing capitalist system.

Indeed, what was considered as a *frictionless* market during pre-crisis periods played, instead, a relevant role in weakening the channels of monetary policy transmission mechanism. In this regard, two main events can be considered as responsible for undermining the global financial stability: (i) the migration from the term to the overnight segment of money markets, due to the rise of interbank interest rates spread; and (ii) the excessive use of the central bank's deposit facility by lending banks, derived from their decreasing willingness to lend out reserves to the interbank market. To take these facts into account, building a framework with interbank market dynamics and banks' funding liquidity practices seems unavoidable. For this reason, this model is intended to study how modern capitalist economies work and how central banking operations affect the real sector, both by emphasising the roles and responsibilities of the banking system, and by modelling the mechanics of bank-to-bank relations.

With the aim of providing a more comprehensive, but still simple, analysis of interbank dynamics and 'of central bank's daily tactics' (Gnos & Rochon, 2011), the starting point of this study can be detected in the functioning of a potential payment system within an overdraft economy, to resemble the Target 2 in the Eurosystem. In this framework, banks can interact among themselves in two segments of the unsecured interbank market, the overnight segment and the term one. This strategy allows to model banks' liability management in the form of *reserves management strategies*, diversified by duration and dependent on banks' past degree of maturity transformation. Indeed, the main feature of this model is the introduction of a measure for banks' maturity mismatch, acting as the driver according to which the borrowing bank will choose whether to demand overnight or term or both kind of interbank contracts. When interbank market transactions are not possible, that is when supply and demand of interbank loans are not matched in duration, they can also have access to the central bank's standing facilities.

To do so, this analysis exploits the setting of Stock-Flow Consistent (SFC) macroeconomic modelling for two reasons. First, because these models depict the dynamics of both the real and the financial sectors of the economy. Second, in an attempt to fill two main gaps within this field of literature, explained in more detail in the next section: (i) the absence of intrasectoral flows considerations, and (ii) the lack of a comprehensive behaviour of the banking system with respect to portfolio choices.

Based on real-world banking practices, liability management considerations should come along with asset choices, which have been the primary focus of SFC models so far, at least for three reasons. First, because the uniqueness of the bank is that 'not only must [it] take an asset position with a stochastic return; it must finance that position with a liability base of uncertain composition' (Dymski, 1988). Second, because in the context of an *overdraft economy*, like the European one, commercial banks do not hold government securities and 'can obtain additional reserves by borrowing them from the central bank' (Lavoie, 2009), making liability management concerns inevitable. Third, because as long as the endogeneity of money, at the core of the SFC framework, makes the amount of loans created in the private sector independent from the amount of reserves issued by the monetary authority, central banks will implement monetary policy by steering short-run interest rates, that is by manipulating banks' funding costs in the interbank market, which, in turn, will have an impact on credit markets.

In the light of this, when dealing with banks' portfolio choices, their *debt maturity structure* decisions should not be neglected. These ones are the key to analyse banks' degree of maturity transformation and the intensity of maturity mismatch in their balance sheets, responsible for their profitability but also for their potential riskiness on the interbank market.

On the one hand, by increasing the maturity gap between their assets and liabilities, that is by short-run funding long-term assets, banks are able to create liquidity.¹ On the other hand, when maturity mismatch practices become excessive, banks could be subject to higher *rollover risk* and *funding liquidity risk*, finding themselves unable to re-access the interbank market, or one of its segments, to raise funds to pay for existing debts.² Thus, the greater the reliance on short-run debt, the more frequently they are supposed to re-access the market, the greater the refinancing vulnerabilities they might face. These practices should be taken into account not only because they have been proven to be consolidated features of modern payment systems, but also because they have been considered relevant drivers of the recent interbank market freeze experienced during the last financial crisis.

As a consequence, by providing more attention to banks' funding practices, which impact their ability to expand credit when needed and the effectiveness of the central bank's operations, the aim of this model is twofold: i) to extend the current structure of SFC modelling by including simple bank-to-bank relations to capture intrasectoral flows; and ii) to analyse the impact of maturity mismatch and funding liquidity risk on the performance of the two segments of the interbank market and on the real economy.

The outline of this paper is as follows. Section 2 presents the literature related to this study. Section 3 describes the institutional context and introduces the characteristics of the model, that is the behaviour of the key agents of the analysis (banks and the central bank), and the penultimate section (section 4) includes the experiments conducted on the baseline scenario. The last section concludes.

2 | LITERATURE REVIEW

Heterodox monetary theories put the banking system at the centre of their analysis. Post-Keynesians, indeed, describe capitalism as a monetised production economy, opposed to the neoclassical paradigm, where money is *never* neutral and results from the flows of credit-debt relations.

In such a world, the well-being of current capitalisms can not be disentangled from the well-functioning of the banking system, and thus, of credit markets and interbank payment transfers.

The banking system is, indeed, rooted in two main interdependent roles, fundamental to determine the level of economic activity (Dymski, 1988), and at the heart of the endogenous monetary theory (EMT) advocated by Post-Keynesians. First, banks create *inside money*, deposits, via lending in the credit market; second, banks manage the flow of payments that derives from the conduct of business in the real sector via accessing the money market, by trading *outside money* or reserves. In performing the first role, they provide elasticity to the economic system by granting loans with no need of any prior reserve constraints, simply by creating deposits *out of thin air*. The quantity of loans so created then influences the amount of reserves that the central bank should issue to net banks' bilateral obligations, and to guarantee settlement for 'payment finality'

¹Banks create liquidity by transforming illiquid or long-term assets, like long-term loans or mortgages, into short-term liabilities, such as sight deposits.

²In the context of this study, funding liquidity risk, that is the risk of not being able to raise funds, is considered in the optic of debt rollover, i.e. the ability of banks to obtain loans to pay for existing debts.

(Gnos & Rochon, 2011). Essentially, any subsequent flows of deposits, deriving from flows of payments between non-bank agents, will induce banks to adjust their balance of reserves. Therefore, independently of the presence or not of reserve requirement regimes, banks need to 'obtain these settlement balances one way or another' (Rochon & Rossi, 2007), either by participating in the money market, through interbank borrowing-lending, or by accessing the central bank's standing facilities.

This mechanism, loans create deposits and deposits create reserves, captures both roles performed by the banking system and is considered as the cornerstone of SFC modelling. However, while the first causal link, loans to deposits, has been extensively discussed in the SFC literature, the second one, going from deposits to reserves, has not yet been exhaustively explored.

To the best of my knowledge, indeed, bank-to-bank relations have not yet been studied in this stream of literature. One possible reason can be detected in the high level of aggregation SFC models have by construction, which confines the analysis to inter-sectoral flows while leaving aside intrasectoral ones.³ More realistic features of the banking system, but exclusively focusing on the credit market, have been provided by Le Heron (2007), Le Heron and Mouakil (2008) and Le Heron (2011). In these *pure* SFC models, the authors generalise household's liquidity preference theory developed by Godley and Lavoie (2006) to private banks' behaviour, with the aim of explaining how banks determine credit. In their setting, a *representative* bank can actively manage its balance sheet by choosing the composition of its asset positions. However, there is no mention about banks' funding choices, that is how banks decide to finance these positions, despite these practices might trigger banks' refinancing troubles, which could be analysed by taking into account their funding liquidity risk or risk of rollover.

Endogenous money theories, both the *horizontalist* and the *structuralist* approaches, still ignore the causes and the consequences of banks' reluctance or inability to rollover debts. Horizontalist authors (Deleidi, 2020; Lavoie, 1996; Moore, 1991) support the idea of a fully accommodative central bank, behaving as a 'reserve price setting' authority and unable to control reserve quantities: in this framework, additional reserves can only be obtained by borrowing from the central bank and credit market rates are set through an exogenous markup rule. This idea of banks not being 'quantitative-constrained for reserves' (Moore, 1991) and the consequent exogeneity of the price of money is, instead, contradicted by the other side of the debate. Among the proponents of the *structuralist* view, Pollin (1991) admits the relevance of bank's liabilities management practices in the short-term money market, which resemble interbank interactions, but only in the light of the central bank's ability to impose quantitative constraints on reserves. In

³As a way to solve this drawback, aggregative techniques have been combined with disaggregative ones, for example by merging SFC with Agent-Based models (AB-SFC models). As part of this recent stream of literature, Caiani et al. (2016) develop the so-called *benchmark model* for macroeconomics to analyse possible financial frictions. This study allows for banks' active management of balance sheets and endogenous evolving strategies, focusing uniquely on the creation of loans and *quantity rationing mechanisms* in the credit market. On this already existing framework, Schasfoort et al. (2017) add interbank market interactions and include banks' funding costs as influencing the determination of interest rates in the credit market, in order to test the strength of the various channels of monetary policy transmission mechanism. Last, Reissl (2018) studies banks' heterogeneous expectations formation with the inclusion of bank-to-bank relations, by adopting a more hybrid technique in which all sectors, except for the banking one, are treated in aggregate terms.

Despite the fact that these hybrid AB-SFC models formalise interbank relations in the attempt to study either the central bank's transmission mechanism or banks' expectations, the interbank market has been still 'modelled in a fairly simple fashion' (Reissl, 2018), to the detriment of realism.

this context, the endogeneity of money is twofold: both its quantity and its price are endogenous, the latter being determined from the interaction between the monetary authority and the actors within the financial market.

With respect to the purpose of this paper, two main limitations are faced by the current Post-Keynesian theory of central banking. On the one hand, the interbank market appears to be needed *only* in case of a non-accommodative behaviour of the central bank, neglecting the elasticity it might provide in the context of payment settlements. On the other hand, an ultra-accommodative behaviour of the monetary authority would induce banks to use their excess reserves either in 'lending to deficit banks or in reimbursing the central bank for their pre-existing debt' (Rochon & Rossi, 2007). However, the huge amount of liquidity hoarded at the central bank during the last financial crisis might suggest that banks' unwillingness to trade in the interbank market, or to rollover funds, deserves much more attention by heterodox monetary theory.

As an evidence arose from the recent financial distress, rollover risk, deriving from maturity mismatches and banks' funding choices, impacted the segments of the interbank market from various routes. Secured interbank transactions have been impaired because increasing rollover risk has caused a reduction in the value of collateral (Acharya et al., 2011), and rising systemic risk (Anand et al., 2012). In the unsecured segment, the higher term borrowing costs for interbank loans⁴ induced lending banks to only lend on the overnight interbank market or else to hoard liquidity at central bank, forcing borrowing banks to migrate to the overnight segment, even further exacerbating maturity mismatch and rollover risk, or to take advances from the central bank (Acharya & Skeie, 2011).

To conclude, pure SFC frameworks with a more realistic representation of the banking system still ignore banks' liability side and the relevance of funding costs on the determination of credit market rates, which can be captured only by modelling interbank market interactions and by merging the dyadic determination of interest rates emerged from the two sides of the aforementioned Post-Keynesian debate.

3 | THE MODEL

A SFC model can be built following the steps described in Le Heron and Mouakil (2008). First, the two matrices at the core of SFC modelling need to be defined: the balance sheet matrix and the transaction flow matrix. These two matrices are complementary for describing the modelled economic system as a whole. The second step requires to count the variables, to assign them to the agents in each sector, and to transcribe the accounting identities arising from the transaction matrix, see Appendix A for details. Finally, it will be necessary to build the whole model by defining each unknown either through a behavioural equation or through an accounting identity.

3.1 | Institutional context and matrices

The postulated economy consists of five sectors: the government, households, firms, banks and the central bank. While the first three sectors will be modelled according to already existing

⁴By engaging in term interbank contracts, borrowing banks can re-access the market to raise funds less frequently. This reduced refinancing frequency causes the inability of the lending bank to constantly update its information about the borrowing bank's creditworthiness, making term loans more risky from the lender's perspective.

contributions in the stream of SFC literature, the innovations in the present analysis will mainly concern the financial sector, that is the behaviour of banks and the central bank, which will be briefly explained in this section.

The government issues short-term bills (B), held by banks as liquidity buffer, and bought residually by the central bank. Indeed, on the grounds of the European institutional context, modelling an *overdraft economy* requires two considerations. First, commercial banks can not exchange government securities with the central bank when in need of reserves; 'on the contrary, private banks [...] are permanently in debt vis-à-vis the central bank, having borrowed funds [...] to acquire the reserves that they are legally required to hold' (Godley & Lavoie, 2006), or to settle interbank payments. Second, the central bank should be modelled both in its accommodating role, and in its disciplinary one. Indeed, not only the monetary authority provides elasticity through its *money-purveying role* (Rochon & Rossi, 2011), via marginal refinancing operations and accommodating advances to banks in reserve shortage, but it also functions as a *discipline provider*, by setting the interest rate corridor and regulatory requirements, while intervening as backstop agent to whom banking institutions recur 'in absence of any other convenient alternative within the interbank market' (Bianchetti & Carlicchi, 2013).

In the context of this analysis, the central bank's balance sheet is almost 'perfectly lean' (Bindseil, 2004), composed by high-powered money on the liability side and monetary policy operations on the asset side, with no autonomous components.

Among the monetary policy operations on the asset side, three elements will be considered. First, overdrafts (Ovd), that is intraday credit provided on demand to a bank in shortage of reserves for interbank payment purposes. Indeed, 'the provision by central banks of intra-day credit in payment systems, [...] is a relatively new kind of open-market operation' (Allen, 2007). Second, the central bank acts as a residual purchaser of short-term government securities (B_{cb}), as it is usually assumed in SFC models. Last, the lending facility (R_{cb}^l) is a passive liquidity-injecting operation used 'at the discretion of individual commercial banks' (Bindseil & Würtz, 2007) when the interbank market is reluctant to lend.

About the liability side, first, the monetary base is expressed in terms of high-powered money (HPM), representing current reserve accounts held by banks to fulfil their reserve requirements; second the deposit facility (R_{cb}^d), a *liquidity-absorbing* passive operation that can be used by commercial banks with a surplus of reserves not lent out on the interbank market.⁵ While the use of the two standing facilities by commercial banks will be extensively discussed in another section, two aspects are still worth noticing at this stage. First, the potential surplus of reserves derives both from the conduct of business, and the possible accumulated use of the central bank's deposit facility, constituting together the amount of free reserves⁶ that can be lent out to the interbank market. Second, these holdings are not provided or accommodated by the central bank, instead, they 'must come at the expense of another commercial bank being unable to meet its reserve requirement' (Rule, 2015).

In the attempt to build a payment system framework with more realistic features of the financial system within an overdraft economy, the two main goals of the European Real Time Gross Settlement system (Target 2) should be considered: meet reserve requirements and make payments (Rainone, 2017). For the sake of simplicity, considerations about collateral requirements and

⁵Instead of including *net standing facility* as a single element in the asset side, expressed as the difference between the deposit facility and the lending one (netting on the asset side), the two operations have been separated to have a clearer representation of the central bank's balance sheet.

⁶Free reserves are defined as the amount of reserves not contributing to the fulfilment of the reserve requirement.

TABLE 1 Initial balance sheets

Bank j		Bank k		CB	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
L_f	D_f	L_h	D_h	Ovd_j	HPM_j
HPM_j	Ovd_j	HPM_k	Ovd_k	Ovd_k	HPM_k

National Central Banks will be left aside.⁷ Payments in a monetised production economy take the form of deposit flows between banks' balance sheets. When banks' customers order payments in favour of other agents, two cases can be distinguished. Either the two agents hold deposits at the same bank, in which case a simple deposit transfer in the bank's liability side will occur. Or, the two agents are customers of different banks, in which case deposit outflows and inflows have to be considered. In this framework, the simple case of deposit transfer will be excluded from the analysis for two reasons. First, because it does not require a consequent adjustment of reserve holdings. Second, because what is interesting are payment liquidity shocks that manifest themselves in the form of deposit outflows and represent a source of banks' uncertain liquidity needs (Bucher et al., 2014), impacting banks' reserve positions. Indeed, 'it's important to consider the effects of a net outflow of one bank, tantamount the net inflow to the other bank' (Bindseil & König, 2012).

For this purpose, the banking sector will be considered as composed of two banks, bank j and bank k from now on. While bank j grants loans to firms (L_f) to finance production, bank k provides short-term loans only to households (L_h) for consumption purposes. Firms hold money balances at bank j (D_f) and households hold deposits at bank k (D_h). Both banks hold reserve accounts at the central bank (HPM_j , HPM_k) to fulfil their reserve requirements. In terms of balance sheets, the initial situation is the one described in Table 1, leaving aside for the moment the central bank's standing facilities.

Now, let us suppose that firms make wage payments W to households. Since the two agents hold deposits in two different banks, this payment flow implies a transfer of deposits from bank j to bank k .⁸ This establishes a debt-relationship between the two institutions, whose final settlement must occur in central bank's money, thus via reserves deposits held at the monetary institution. Therefore, this monetary transfer results as a triangular relationship, since all 'payments among commercial banks have to be intermediated by a third agent, usually the central bank' (Graziani, 2003).

Table 2 summarises what happens when a payment between two different banks must be made within this setting, as modelled by Whelan (2014) and Febrero and Uxó (2013).

Next, assuming that banks operate 'in a system without averaging, thus with a one-day reserve maintenance period' (Bindseil, 2004), two cases can be taken into account. If bank j has sufficient reserves holdings for the payment to occur, a simple transfer in the central bank's balance sheet from HPM_j to HPM_k will happen, and bank j will subsequently need to

⁷Therefore, it is assumed that there is no *division of labour* among the departments of the monetary authority, such that the NCB, usually responsible for the payment system department, coincides in this context with the institution responsible for monetary policy implementation (the ECB).

⁸For the sake of simplicity, deposit outflows deriving from households' consumption decisions are excluded in this model, that is no deposit outflows derive from consumption expenses to firms' deposits held at bank j . This choice has been intended to reflect the idea that in 'normal times' the firm (household) sector usually assumes a net borrowing (lending) position. Certainly, further developments of the model should relax this assumption and allow for a two-sided deposit outflow.

TABLE 2 Payment flow

Household		Bank <i>j</i>		Bank <i>k</i>		Firm		CB	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
$D_h[+W]$		$HPM_j[-W]$		$D_f[-W]$		$D_h[+W]$		$HPM_j[-W]$	
		$HPM_k[+W]$						$HPM_k[+W]$	

Note: Potential changes in households' net worth or firms' inventories are not taken into account to provide a clearer representation of the payment flow.

acquire reserves only to replenish its reserve requirement holdings. Otherwise, if bank j is in shortage of reserves, that is when HPM_j is not enough to cover the payment, it will ask for overdrafts or advances (Ovd_j) to the central bank in the form of intraday credit, which will be provided on demand to guarantee immediate settlement and bear no interest rate.⁹ This establishes a debt relationship between bank j and the central bank and bank j will then need reserves both to repay the credit received from the central bank, and to fulfil its reserve requirement. The central bank will then settle the payment by transferring reserves from bank j to bank k on the liability side of its balance sheet. The overdrafts demanded by bank k (Ovd_k) are assumed to act as a buffer variable in its balance sheet.

At this point, bank j will need again to acquire reserves in both cases, either only to fulfil its reserve requirement, or also to repay the central bank for the advances provided. In the context of this paper, the reserves that bank j will have to re-acquire refer only to the ones needed to repay the overdrafts received for payment settlement purposes. It will have the possibility to choose between asking for reserves in the interbank market from bank k , whose surplus of reserves derives from the payment flow just transferred plus any potential accumulation of free reserves at the central bank's deposit facility, or from the central bank by accessing the lending facility at penalty rate. The exogenous structure of the outside spread, or corridor, set by the central bank should ensure that banks in shortage of reserves at this stage will first try to fulfil their needs in the interbank market. About the latter, banks have the possibility to choose whether to demand, and supply, overnight interbank loans (IB_{on}) or term ones (IB_{term}). The conditions of this decision will be explained in the subsequent sections.

From these initial considerations, the balance sheet matrix in Table 3 describes the stocks held by each agent in each sector, providing a static picture of the economic system in question. Intersectoral monetary transactions and the flow of funds are captured by the transaction matrix in Table 4, which depicts the dynamics of the system.¹⁰ Figure 1 reports the complete balance sheet composition of all the agents after having disaggregated the balance sheet matrix. By doing so, it is easier to grasp the overall situation in terms of holdings of assets and liabilities. The only real assets in the model, with no liability counterpart, is physical capital held by firms.

Following the institutional context described in this section, only the behaviour of the central bank and of the two banks will be described.¹¹ All the parameters and exogenous variables both in the matrix and in the whole model are reported with a bar.

The behaviour of the remaining agents in the model is included in Appendix A.

3.2 | Central bank

The central bank sets banks' compulsory reserve requirements, Equations (1) and (2), as a share of agents' past deposits.

⁹This kind of credit is not remunerated as in the example provided by Whelan (2014), and as specified by Allen (2007) (p. 42).

¹⁰For the sake of clarity, the buffer variables are indicated in bold. Those are the ones defined in the model through the use of accounting identities.

¹¹The equations included in the system are numbered via Arabic numerals (1, 2, ...), and through a combination of both Arabic and Roman numbers when the accounting identities are used (e.g. 3-xv, 6-ix, ...), see Appendix A. Instead, all the other equations used only as explanatory purposes are either within the text, or denoted via the set of letters in the alphabet (a, b, ...).

TABLE 3 Balance sheet matrix

	Households	Firms	Government	Central bank	Banks Bank <i>j</i>	Bank <i>k</i>	Σ
Capital stock (<i>K</i>)		+ <i>K</i>					+ <i>K</i>
Deposits (<i>D</i>)	+ <i>D_h</i>	+ <i>D_f</i>			− <i>D_f</i>	− <i>D_h</i>	0
Loans (<i>L</i>)	− <i>L_h</i>	− <i>L_f</i>			+ <i>L_f</i>	+ <i>L_h</i>	0
Bills (<i>B</i>)			− <i>B</i>	+ <i>B_{cb}</i>	+ <i>B_j</i>	+ <i>B_k</i>	0
Bonds (<i>B^{lr}</i>)			− <i>B^{lr}</i>		+ <i>B^{lr}</i>		0
Overdrafts (<i>Ovd</i>)				+ <i>Ovd</i>	− <i>Ovd_j</i>	− <i>Ovd_k</i>	0
Required Reserves (<i>HPM</i>)				− <i>HPM</i>	+ <i>HPM_j</i>	+ <i>HPM_k</i>	0
Overnight Interbank Loan (<i>IB_{on}</i>)					− <i>IB_{on}</i>	+ <i>IB_{on}</i>	0
Term Interbank Loan (<i>IB_{term}</i>)					− <i>IB_{term}</i>	+ <i>IB_{term}</i>	0
Lending Facility Reserves (<i>R_{cb}^l</i>)				+ <i>R_{cb}^l</i>	− <i>R_{cb}^l</i>		0
Deposit Facility Reserves (<i>R_{cb}^d</i>)				− <i>R_{cb}^d</i>		+ <i>R_{cb}^d</i>	0
Net Wealth: Σ	+ <i>V_h</i>	+ <i>V_f</i>	− (<i>B</i> + <i>B^{lr}</i>)	0	+ <i>V_{bj}</i>	+ <i>V_{bk}</i>	+ <i>K</i>

$$HPM_j = \bar{u} D_{f(-1)} \quad (1)$$

$$HPM_k = \bar{u} D_{h(-1)} \quad (2)$$

$$HPM = HPM_j + HPM_k \quad (3\text{-xvi})$$

Moreover, it is assumed to be accommodating with respect to the advances demanded by both banks, as expressed in Equations (5–6-viii). While bank *k*'s demand for overdrafts acts as a buffer variable, the amount of overdrafts demanded by bank *j* is crucial for how the interbank market works in this model, which is explained in the next section.

$$Ovd \equiv Ovd_j + Ovd_k \quad (4\text{-xv})$$

$$Ovd_j = D^{Ovd} \quad (5)$$

$$Ovd_k = Ovd_{k(-1)} + \Delta HPM_k + \Delta B_k + \Delta L_h + \Delta IB_{on} + \Delta IB_{term} + \Delta R_{cb}^d - P_{bk}^u - \Delta D_h \quad (6\text{-viii})$$

TABLE 4 Transaction flow matrix

Operation	Firm			Banks			Bank <i>k</i>			Central bank		
	Household	Current		Capital	Bank <i>j</i>		Capital	Current		Capital	Current	
		Current	Capital		Current	Capital		Current	Capital		Current	Capital
Consumption	$-C$	$+C$										
Government Expenditure		$+G$										
Business Investments		$+I$	$-I$									
Wages	$+W$	$-W$										
Taxes	$-T$											
Interest on Bills					$+i_b B_{j(-1)}$			$+i_b B_{k(-1)}$		$+i_b B_{cb(-1)}$		
Interest on Bonds					$+i_b^{lr} B_{j(-1)}^{lr}$						$-i_b^{lr} B_{cb(-1)}^{lr}$	
Interest on Loans	$-i_{jk(-1)}^{l} L_{jk(-1)}$	$-i_{j(-1)}^{l} L_{j(-1)}$			$+i_{j(-1)}^{l} L_{j(-1)}$			$+i_{jk(-1)}^{l} L_{jk(-1)}$				
Interest on Deposits	$+i_{jk(-1)}^{d} D_{jk(-1)}$	$+i_{j(-1)}^{d} D_{j(-1)}$			$-i_{j(-1)}^{d} D_{j(-1)}$			$-i_{jk(-1)}^{d} D_{jk(-1)}$				
Interest on IB_{on}					$-i_{jk(-1)}^{on} IB_{on(-1)}$			$+i_{bk(-1)}^{on} IB_{on(-1)}$				
Interest on IB_{term}					$-i_{jk(-1)}^{term} IB_{term(-1)}$			$+i_{bk(-1)}^{term} IB_{term(-1)}$				
Interest on Lending Facility					$-i_{cb(-1)}^{l} R_{cb(-1)}^l$					$+i_{cb(-1)}^{l} R_{cb(-1)}^l$		
Interest on Deposit Facility								$+i_{cb(-1)}^{d} R_{cb(-1)}^d$				
Profits of firms	$+Div_f$	$-P_f$	$+P_f^u$									
Profits of bank <i>j</i>	$+Div_{bj}$				$-P_{bj}$	$+P_{bj}^u$						
Profits of bank <i>k</i>	$+Div_{bk}$							$-P_{bk}$	$+P_{bk}^u$			
Profits of CB										$-P_{cb}$	$+P_{cb}$	
Δ Deposits	$-ΔD_h$		$-ΔD_f$			$+ΔD_f$			$+ΔD_h$			
Δ Loans	$+ΔL_h$		$+ΔL_f$			$-ΔL_f$			$-ΔL_h$			
Δ Bills						$-ΔB_j$			$-ΔB_k$	$-ΔB_{cb}$	$+ΔB$	

TABLE 4 (Continued)

Operation	Firm		Banks		Central bank			
	Household	Current	Capital	Bank j		Bank k		
						Capital	Current	Capital
Δ Bonds						$-\Delta \mathbf{B}^{\text{lr}}$		$+\Delta \mathbf{B}^{\text{lr}}$
Δ HPM					$-\Delta \text{HPM}_j$	$-\Delta \text{HPM}_k$	$+\Delta \text{HPM}$	
Δ Overdrafts					$+\Delta \text{Ovd}_j$	$+\Delta \text{Ovd}_k$	$-\Delta \text{Ovd}$	
ΔIB_{on}					$+\Delta IB_{on}$	$-\Delta IB_{on}$		
ΔIB_{term}					$+\Delta IB_{term}$	$-\Delta IB_{term}$		
Δ Lending Facility					$+\Delta R^l_{cb}$		$-\Delta R^l_{cb}$	
Δ Deposit Facility						$-\Delta R^d_{cb}$	$+\Delta R^d_{cb}$	
Net Lending Position	$-\Delta L_h$	$-\Delta L_f$	$+\Delta L_f$	$-\Delta L_{bj}$	$+\Delta L_{bj}$	$+\Delta L_{bk}$	$-\Delta L_{cb}$	$-\Delta L_g$
Σ	0	0	0	0	0	0	0	0

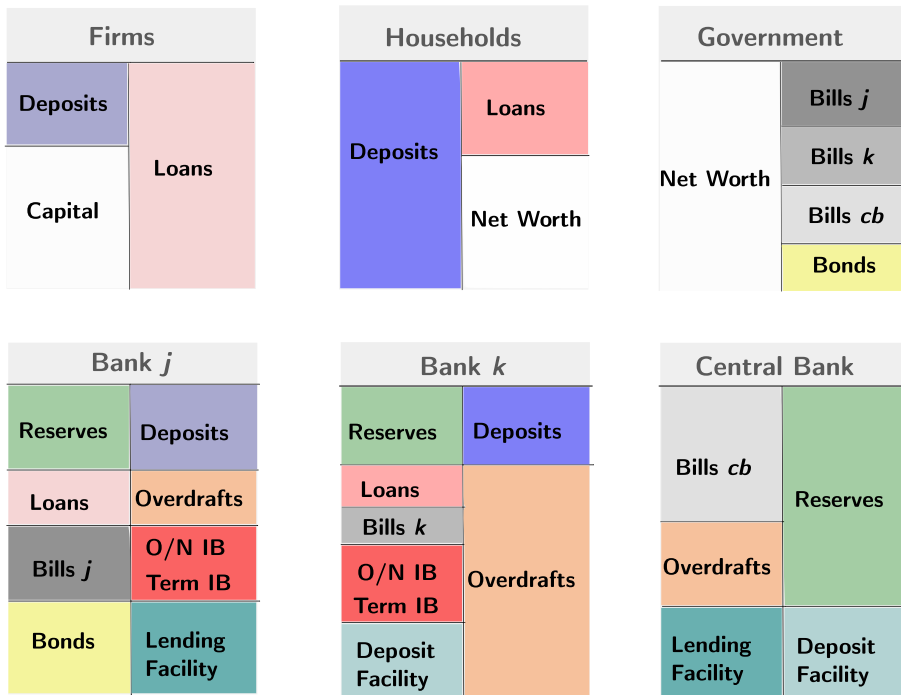


FIGURE 1 Agents' balance sheet composition [Colour figure can be viewed at wileyonlinelibrary.com]

Among the roles of the monetary authority, it sets the outside spread by defining the ceiling rate, i_{cb}^l , and the floor rate, i_{cb}^d , both exogenous in this context. This interest rate corridor must ensure that bank j will first try to look for reserves on the interbank market, before accessing the central bank's lender of last resort function. In the framework of this model, the corridor is assumed to be *symmetric*. This implies that the targeted interest rate, i_{cb}^t , is located exactly in the middle between the two policy rates, captured by their average as in Equation (7). Indeed, it is expressed as the weighted average of the two standing facility rates, where '[t]he weights are the probabilities associated with the need to take recourse to either of the two facilities' (Bindseil, 2014), which are assumed to be equal in a symmetric corridor approach.

Central bank's profits are expressed through identity (ix), and are assumed to be fully transferred to the government.

$$i_{cb}^t = \frac{\bar{i}_{cb}^l + \bar{i}_{cb}^d}{2} \quad (7)$$

$$P_{cb} \equiv i_b B_{cb(-1)} + \bar{i}_{cb}^l R_{cb(-1)}^l - \bar{i}_{cb}^d R_{cb(-1)}^d \quad (8\text{-ix})$$

Last, the monetary authority acts as a residual purchaser of government securities to clear the bills market (Equation 9-xiv).

$$B_{cb} \equiv B - B_j - B_k \quad (9\text{-xiv})$$

3.3 | Banks

The goal of the present study is to provide a more complex formalisation of the banking system by the inclusion of potential bank-to-bank relations. For this purpose, first the interbank market setting will be introduced, and then the design of the credit market will be taken into account.

The interbank market intervenes to smooth those payment liquidity shocks that arise from outflows of deposits. In this context, considerations about banks' rollover risk, that is their ability to re-access the market to pay for existing debts (central bank's advances), can not be disregarded. The risk of rollover is analysed through banks' funding choices about their debt maturity structure, which can be modelled by taking into account two kinds of funding strategies: overnight versus term (3w–12m).

On the one hand, a potential borrowing bank (bank j) might choose whether to ask for overnight or term interbank funds; on the other, a potential lending bank (bank k) might be willing to accommodate the demanded duration or not, potentially leading to frictions¹² in the market.

Therefore, choices about the maturity structure of debt are focused on the duration of interbank loans within the unsecured money market segment, and are linked to banks' maturity mismatch and their degree of maturity transformation. From the borrowing bank's perspective, the premise is the following: the higher the amount of overnight interbank loans (IB_{on}), the higher the degree of maturity transformation, which translates into higher rollover risk. The opposite in the case of increasing reliance on term interbank loans (IB_{term}).

According to Bologna (2018), a *quantity-based* measure for maturity mismatch, able to capture the misalignment in expiration dates between assets and liabilities, also detects banks' *structural* rollover risk, and is an accurate proxy for their funding liquidity risk. For this purpose, this study exploits the Net Stable Funding Ratio (NSFR) established by Basel III, which is constructed by taking into account the residual maturities of the items in banks' balance sheet, and can be interpreted as a measure for maturity mismatch and funding liquidity risk. Indeed, this regulatory requirement is expressed as a ratio between the weighted sum of liabilities and the weighted sum of assets, in which the weights are computed according to the residual contractual maturity of the components of the two sides of the balance sheet. This ratio is formalised as follows:

$$NSFR = \frac{\text{Total Available Stable Funds (TASF)}}{\text{Total Required Stable Funds (TRSF)}} = \frac{\sum_i a_i L_i}{\sum_n b_n A_n} \quad (a)$$

About the numerator, TASF captures the proportion of capital and liabilities with a duration greater than one year (1y). Each liability is assigned to a certain category according to the *degree of stability* it carries, which is linked to its residual duration. Then, the so-called *ASF risk factor* is assigned to each category, which represents a weight based on residual maturity, and is comprised between zero and one, such that when the ASF factor is equal to zero, the degree of stability is null, and when it is equal to one, the degree of stability is maximum. Therefore, as ASF increases, the higher the maturity of liabilities, the higher the degree of stability. As regards the

¹²Financial frictions occur when trades can not take place because the market is incomplete, either because the market does not exist, or because parties are unwilling to engage in certain contracts, as specified by Caiani et al. (2016).

denominator, TRSF represents the amount of stable funding *required* to be held given liquidity characteristics and residual maturities of the assets in banks' balance sheet. Each asset is thus categorised according to its *value of exposure*, which is linked to its degree of liquidity or *power of disposal*.¹³ An *RSF risk factor* equal to zero indicates fully liquid assets; instead, an RSF factor equal to one represents illiquid assets, with maturity greater than one year, that must be entirely refinanced by *stable funding*.

In the light of these considerations, the NSFR can be interpreted as a measure for bank's *degree of stability*, according to which, in this context, the borrowing bank (bank *j*) can choose the demanded duration of interbank loans, overnight versus term. The logic is the following. The degree of stability is low either when TASF decreases, or when TRSF increases. In this event, it would be plausible to think that the borrowing bank would seek to engage in more stable funding strategies, term interbank loans implying less refinancing legs, since it becomes more concerned about its ability to re-access the market in the future. Hence, its decreasing reluctance to bear the burden of longer debt maturities might translate into higher demand for term loans in the interbank market, which would allow to increase the bank's degree of stability by lowering its maturity mismatch. However, whether they will be able to operate via a more matched balance sheet will depend on the lending bank's willingness to engage in term contracts, whose conditions are explained in detail in the following paragraphs.

To capture this mechanism, it could be useful to establish a *minimum stable funding requirement*, following De Haan and van den End (2013).¹⁴ Since Basel III determines that the ratio above must be at least equal to 100%, the weighted sum of liabilities must be at least equal to the weighted sum of assets. Formally,

$$\sum_i a_i L_i \geq \sum_n b_n A_n; \quad (b)$$

by summing up and denoting the unweighted sum of liabilities and the unweighted sum of assets, respectively, as $L_m = \sum_i L_i$ and $A_m = \sum_n A_n$, the condition above can be re-written as follows:

$$a_m L_m \geq b_m A_m; \quad (c)$$

with $a_m = \frac{\sum a_i L_i}{\sum L_i}$ and $b_m = \frac{\sum b_n A_n}{\sum A_n}$.

Last, by dividing for a_m , it is possible to derive the minimum stable funding requirement as $L_m = \left(\frac{b_m}{a_m}\right) A_m$. At this point, two cases are possible. When $L_m < \left(\frac{b_m}{a_m}\right) A_m$, the NSFR is not satisfied and the borrowing bank might prefer to borrow term. On the contrary, when the so-called *desired margin of stable funds*¹⁵ is satisfied, in other words when $L_m \geq \left(\frac{b_m}{a_m}\right) A_m$, the borrowing bank's balance sheet will have a high degree of stability correspondent to a low degree of maturity transformation, and it might be more willing to ask for overnight loans on the interbank

¹³In Dafermos (2012), the power of disposal of an asset is negatively linked to four kinds of risks: illiquidity risk, income risk, capital risk, and risk of default. Hence, as one of these perceived risks increases, the power of disposal decreases. In the context of this study, the power of disposal of an asset is exclusively interpreted in light of its embodied risk of liquidity, expressed in terms of the residual contractual maturity.

¹⁴In their paper, the authors follow a similar procedure based on the Liquidity Coverage Ratio.

¹⁵This is similar to the *Desired Margin of Safety* in Nikolaidi (2014), Miess and Schmelzer (2016) and Dafermos (2012). The difference is that in these cited models they establish a Desired Margin of Safety that is linked to households' or firms' targeted leverage ratio, to be compared to an actual leverage ratio.

market. This interpretation is embodied in bank j 's decision for overnight interbank loans through Equation (10), which defines the bank's degree of stability as an inverse measure for maturity mismatch.

$$DS_m = L_m - \left(\frac{b_m}{a_m} \right) A_m \quad (10)$$

Equations (11)–(14) define the elements composing the minimum stable funding requirement, following the implicit contractual maturities and the respective associated weights of Table 1 in Appendix B. More specifically, Equations (13) and (14) represent, respectively, the proportion of available stable funds over total funds, and the fraction of required stable funding over total assets.

$$L_m = D_{f(-1)} + \text{Ovd}_{j(-1)} + IB_{on(-1)} + IB_{term(-1)} + R_{cb(-1)}^l \quad (11)$$

$$A_m = L_{f(-1)} + \text{HPM}_{j(-1)} + B_{j(-1)} + B_{(-1)}^{lr} \quad (12)$$

$$a_m = \frac{\bar{m}_4 D_{f(-1)} + \bar{m}_5 IB_{term(-1)}}{L_m} \quad (13)$$

$$b_m = \frac{\bar{m}_1 L_{f(-1)} + \bar{m}_2 B_{j(-1)} + \bar{m}_3 B_{(-1)}^{lr}}{A_m} \quad (14)$$

At this point, it is possible to introduce the behaviour of the two banks in the interbank market.

3.3.1 | Interbank market

As a consequence of the functioning of the payment system explained in the previous sections, bank j may ask for advances at the central bank if it has not sufficient reserve deposits to make the transfer for wage payments purposes (W) to the household sector, defined in Appendix A. Its demand for overdrafts (D^{Ovd}) can be summarised by the following piece-wise linear function:

$$D^{\text{Ovd}} = \begin{cases} W - \Delta \text{HPM}_j & \text{if } W \geq \Delta \text{HPM}_j \\ 0 & \text{otherwise} \end{cases} \quad (15)$$

At this point, bank j needs to re-acquire reserves, since it is assumed that banks operate in a simple reserve maintenance period of one day. First, it will seek to fulfil its demand on the interbank market in order to repay the central bank for the advances accommodated (IB^D), Equations (16)–(18). The two segments of the interbank market can be considered as complementary, hence bank j can borrow at the same time both overnight and term, as also specified by Abbassi et al. (2014). To capture this, the amount demanded overnight is expressed as a fraction θ of total quantity (IB_{on}^D), and the term demand is residually defined (IB_{term}^D).

$$IB^D = IB_{on}^D + IB_{term}^D = D^{\text{Ovd}} \quad (16)$$

$$IB_{on}^D = IB^D \theta \quad (17)$$

$$IB_{term}^D = IB^D - IB_{on}^D \quad (18)$$

$$\begin{aligned} \theta = & \bar{\alpha} + \bar{\alpha}_1 (\bar{i}_{cb}^l - i_{ib}^{on}) + \bar{\alpha}_2 (i_{ib}^{term} - i_{ib}^{on}) + \bar{\alpha}_3 \frac{DS_m}{V_{bj(-1)}} - \bar{\alpha}_4 (\bar{i}_{cb}^l - i_{ib}^{term}) - \\ & - \bar{\alpha}_5 \overline{PDU} \end{aligned} \quad (19)$$

Equation (19) defines θ , which is interpreted as bank j 's *willingness to borrow overnight*, comprised between zero and one. This fraction is dependent on an autonomous component α and other five elements. First, the opportunity cost of accessing the central bank's standing facility at penalty rate \bar{i}_{cb}^l instead of borrowing overnight at i_{ib}^{on} . When the difference between the two interest rates decreases, in other words, when the overnight interbank rate increases, given \bar{i}_{cb}^l , borrowing from another bank is less profitable, hence θ decreases.¹⁶ The same reasoning can be applied to the second element, the difference between the cost of borrowing term i_{ib}^{term} and overnight.

Third, the fraction θ is positively related to bank j 's degree of stability, expressed in light of the elements of the minimum stable funding requirement defined in Equations (11)–(14). Thanks to this specification, it is possible to capture the bank's funding risk as the driver according to which bank j will prefer to borrow either overnight, or term, or both. Specifically, as DS_m increases, that is when either L_m increases or A_m decreases, the bank has a higher degree of stability and a lower maturity mismatch, thus it would be more willing to borrow overnight, hence θ would increase.

Fourth, the outside spread between the central bank's penalty rate and the term interbank interest rate is negatively related to θ . Indeed, as i_{ib}^{term} increases, reducing its distance from the central bank's ceiling rate, θ would increase and the borrowing bank might become more willing to borrow overnight rather than term. Moreover, as both i_{ib}^{on} and i_{ib}^{term} get closer (or also higher for the term interest rate) to the penalty rate, bank j would prefer not to borrow on the interbank market at all.

The last element influencing bank j 's willingness to borrow overnight is the so-called *perceived degree of uncertainty (PDU)*, defined as in Dafermos (2012). As uncertainty decreases, bank j 's desired degree of maturity transformation increases (Dymski, 1988), and, along with it, the amount it would borrow overnight rather than term.

About the behaviour of the lending bank, three aspects must be analysed: free reserves position, ability and willingness to lend, and preferences for maturity.

One of the assumptions of this study is that both banks hold reserves just to meet their reserve requirements. As a consequence, any potential surplus position of bank k derives from the conduct of business and from the accumulated use of the central bank's deposit facility (R_{cb}^d), as previously specified. Moreover, since the interbank market can not create reserves *out of thin air*, contrary to what happens on the credit market with respect to deposits, what a potential lending bank can lend out to other banks is constrained to the surplus of reserves it holds, referred to as *loanable funds on the interbank market* (LF_k). In the light of these factors, bank k 's ability to lend, as expressed in Equation (20), is represented by the maximum amount of reserves it can provide to bank j on the interbank market.

¹⁶Since by construction the overnight interbank interest rate falls within the corridor (Equation 31), it can get only closer to the penalty rate, not higher. This reasoning does not apply for the term interbank rate (Equation 33), at least not in the baseline scenario.

$$LF_k = W + R_{cb(-1)}^d \quad (20)$$

In Equations (21–23), a share of the total loanable amount (IB^S) is lent out overnight (IB_{on}^S), and the residual in the form of a term interbank contract (IB_{term}^S). This share is defined by the so-called *lending bank willingness* ($L_b W$), similar to Le Heron (2007), Le Heron and Mouakil (2008) and Le Heron (2011).

$$IB^S = IB_{on}^S + IB_{term}^S = LF_k \quad (21)$$

$$IB_{on}^S = IB^S (L_b W) \quad (22)$$

$$IB_{term}^S = IB^S - IB_{on}^S \quad (23)$$

$$L_b W = \bar{\sigma} + \bar{\sigma}_1 \overline{PDU} + \bar{\sigma}_2 (i_{ib}^{on} - \bar{i}_{cb}^d) + \bar{\sigma}_3 (|DER_j| - \bar{\gamma}) - \bar{\sigma}_4 (i_{ib}^{term} - i_{ib}^{on}) - \bar{\sigma}_5 (i_{ib}^{term} - \bar{i}_{cb}^d) - \bar{\sigma}_6 QR \quad (24)$$

The $L_b W$ is a measure comprised between zero and one which captures the lending bank's willingness to lend overnight, similar to θ , and is influenced by several elements. First, an autonomous component expressed via σ . Second, to cope with a rising uncertainty, expressed via an increase in PDU , the lending bank might be more willing to lend overnight. Indeed, by forcing the borrowing bank to re-access the market more frequently, bank k might have the advantage to assess more constantly bank j 's ability to repay the loan at each refinancing round.¹⁷ The lending bank's audit practices are extremely important in the context of the interbank market since, in real-world habits, 'each bank monitors the activities of coparticipants in the market and hence the whole system amounts to conducting a peer monitoring mechanism among the participating bank' (Murinde et al., 2016).

Third, the outside option expressed in terms of the difference between the overnight interbank rate and the floor interest rate of the central bank's deposit facility (\bar{i}_{cb}^d). If the difference between the two rates increases, that is to say that given \bar{i}_{cb}^d , the overnight rate increases, the profitability to lend overnight is higher, thus leading to a rise of $L_b W$.

Fourth, the difference between the borrowing bank's *debt-to-equity ratio* (DER_j), defined in Equation (25) and taken as absolute value to avoid any interpretative confusion, and an exogenous threshold (γ). The logic is as follows. This ratio measures bank j 's current 'financial soundness' (Popoyan et al., 2017). When it decreases, bank j is in a stronger financial position, because either its net worth has increased or its liabilities have decreased. The opposite in the case of increasing DER_j . In terms of bank k 's decision of whether to engage in overnight interbank contracts or term ones, when the difference between this ratio and the exogenous threshold increases, the bank's willingness to lend overnight would increase since, given γ , DER_j would have risen, deteriorating bank j 's capacity to repay its obligations. For the purpose of this study, moreover, this measure

¹⁷In Dafermos (2012), the perceived degree of uncertainty is negatively related to households and firms' targeted burden of debt, such that as PDU increases, agents would desire less leverage. In the case of banks, PDU is negatively linked to their targeted liquidity pressure which impacts credit rationing procedures on the credit market. However, in the context of interbank market dynamics, a potential increase in uncertainty is interpreted in light of the lending bank's maturity preferences. In other words, as the stress felt in the market increases, the lending bank prefers to force the borrowing bank to re-access the market more frequently to raise funds. This is done in order to update its knowledge about the borrowing bank's ability to repay and engage in monitoring activities a higher number of times, by offering overnight interbank loans instead of term ones.

becomes interesting when interpreted in terms of maturity mismatch. Indeed, in the case of negative net worth, which happens when assets are less than liabilities, the bank would be able to operate under these conditions only if its assets mature before its debt obligations, that is it would be left operating until assets mature.

$$DER_j = \frac{Ovd_{j(-1)} + IB_{on(-1)} + IB_{term(-1)}}{V_{bj(-1)}} \quad (25)$$

The fifth element refers to the interbank market spread. When i_{ib}^{term} increases or i_{ib}^{on} decreases, widening their difference, $L_b W$ decreases because bank k 's willingness to lend overnight would diminish. The penultimate term is the spread between the term interest rate and the deposit rate set by the central bank. When i_{ib}^{term} increases, bank k would prefer to lend term rather than overnight, hence $L_b W$ would decrease.

The last term influencing bank k 's willingness to lend overnight is represented by the so-called *quick ratio* (QR), defined in Equation (26). This is assumed to be known by bank k as part of a method 'commonly used in 'real world' bank business models to identify the financial vulnerability of the potential client' (Popoyan et al., 2017), and used in this context as a measure for lenders' preferences for maturity, and not only to assess borrowers' creditworthiness. This ratio measures both the borrowing banks' short-run liquidity position (current assets), and its ability to repay its short-run obligations (current liabilities) with its most liquid assets. The reasoning is the following: when QR increases, the borrower's ability to repay increases. This happens either when the numerator (current assets) increases or when the denominator (current liabilities) decreases. In the light of the lending bank's maturity preferences, it can be plausible to think that as QR increases, as well as bank j 's ability to repay, bank k would become less concerned about constantly assess the borrowing bank's creditworthiness, which could be done by engaging in short-run contracts implying more refinancing legs, overnight interbank funds in this model. As a consequence, bank k 's willingness to lend overnight would diminish. This situation would be reflected by a decrease of $L_b W$ and in the amount lent overnight. On the contrary, when QR decreases, along with bank j 's ability to repay, the lending bank would prefer to engage in contracts with more refinancing frequency to update more regularly the borrowing bank's creditworthiness, that is, in the words of Brousseau et al. (2014), by *inducing refinancing legs for the lender*. Therefore, bank k 's willingness to lend overnight would increase.

$$QR = \frac{L_{f(-1)} + B_{j(-1)} + HPM_{j(-1)}}{Ovd_{j(-1)} + IB_{on(-1)} + R_{cb(-1)}^l} \quad (26)$$

At this point, Table 2 in Appendix B depicts what happens on the interbank market for every possible value of θ and $L_b W$.

In this model, the interbank market is considered to be subject to frictions when the demanded maturities are not matched with the supplied ones. When this occurs, the central bank intervenes as backstop agent, whose standing facilities are used at the initiative of both banks. Indeed, also in the words of Bindseil and Jablecki (2011), the use of liquidity-absorbing and liquidity-providing operations 'may occasionally occur even in normal times, largely due to market frictions'.

As emerges from the first row of Equations (27) and (28), describing the event of a *full* market freeze, when bank j prefers to borrow the full amount demanded (IB^D) from the central bank at

penalty rate by using the lending facility (R_{cb}^l), bank k will also prefer to deposit the full amount of its free reserves (IB^S) at the central bank by accessing the deposit facility (R_{cb}^d). Since this ‘two-sided’ (Bindseil & Jablecki, 2011) recourse to the central bank’s standing facilities happens simultaneously when θ and $L_b W$ take the same values, the *neutrality condition* required under a symmetric corridor approach is satisfied. In other words, the probabilities of the banking system as an aggregate of being *short* and *long* in reserves at the end of the maintenance period might be considered as equal, or, alternatively, the probabilities to access both standing facilities are equal.

$$R_{cb}^l = \begin{cases} IB^D & \text{if } \theta = 0 \text{ and } L_b W = 1 \quad \text{or } \theta = 1 \text{ and } L_b W = 0 \\ IB_{on}^D & \text{if } 0 < \theta < 1 \quad \text{and } L_b W = 0 \\ IB_{term}^D & \text{if } 0 < \theta < 1 \quad \text{and } L_b W = 1 \\ IB_{on}^D - IB_{on}^S & \text{if } \theta > L_b W \\ IB_{term}^D - IB_{term}^S & \text{if } (1 - \theta) > (1 - L_b W) \\ 0 & \text{otherwise} \end{cases} \quad (27)$$

$$R_{cb}^d = \begin{cases} IB^S & \text{if } \theta = 0 \text{ and } L_b W = 1 \quad \text{or } \theta = 1 \text{ and } L_b W = 0 \\ IB_{on}^S & \text{if } \theta = 0 \quad \text{and } 0 < L_b W < 1 \\ IB_{term}^S & \text{if } \theta = 1 \quad \text{and } 0 < L_b W < 1 \\ IB_{on}^S - IB_{on}^D & \text{if } \theta < L_b W \\ IB_{term}^S - IB_{term}^D & \text{if } (1 - \theta) < (1 - L_b W) \\ 0 & \text{otherwise} \end{cases} \quad (28)$$

The stocks of interbank loans can be defined in the light of these considerations. In the credit market, there are no supply constraints, and the stock of loans is determined by banks who incorporate agents’ demand on the supplied amount (see Equations 37 and 39). On the interbank market, instead, supply constraints are determined by the existence and the amount of surplus of reserves in the lending bank’s balance sheet, as already explained. For this reason, a possible strategy to determine the stocks of loans exchanged on the interbank market involves focusing on the *short-side of the market*. To do so, Equations (29) and (30) define, respectively, the stock of overnight interbank loans and the stock of term interbank loans.

$$IB_{on} = \begin{cases} IB_{on}^S & \text{if } IB_{on}^D > IB_{on}^S \\ IB_{on}^D & \text{if } IB_{on}^D < IB_{on}^S \end{cases} \quad (29)$$

$$IB_{term} = \begin{cases} IB_{term}^S & \text{if } IB_{term}^D > IB_{term}^S \\ IB_{term}^D & \text{if } IB_{term}^D < IB_{term}^S \end{cases} \quad (30)$$

This specification seems to be reasonable as long as bank k is not always willing to lend all of its excess funds on the interbank market and accommodate bank j ’s demand for reserves, which is the case in this model.

3.3.2 | Interbank interest rates

The only price-equilibrating mechanism in this analysis occurs on the interbank market, in line with Post-Keynesian theory. Following Reissl (2018), the two interest rates that clear the overnight segment and the term one can be defined according to Equations (31) and (33), with $\bar{\sigma}_{ib}$ exogenous parameter representing banks' sensitivity to excess demand or excess supply captured by Equations (32) and (34). This kind of determination of interest rates in the interbank market resembles the *structuralist* emphasis of the Post-Keynesian debate, since both overnight and term rates are endogenous market prices equilibrating supply and demand, which will impact banks' decisions on the credit market (see Section 3.3.3).

$$i_{ib}^{on} = \bar{i}_{cb}^d + \frac{\bar{i}_{cb}^l - \bar{i}_{cb}^d}{1 + e^{-(\bar{\sigma}_{ib}\epsilon_{on})}} \quad (31)$$

$$\epsilon_{on} = IB_{on}^D - IB_{on}^S \quad (32)$$

$$i_{ib}^{term} = \bar{\eta}_1 + \frac{\bar{\eta}_2}{1 + e^{-(\bar{\sigma}_{ib}\epsilon_{term})}} \quad (33)$$

$$\epsilon_{term} = IB_{term}^D - IB_{term}^S \quad (34)$$

Among the advantages of this formalisation of interest rates, first, it ensures that the overnight interbank rate falls within the central bank's corridor (i_{cb}^d, i_{cb}^l) by construction, since the central bank's objective is to steer short-term interest rates. Moreover, it guarantees that the *equilibrium* interbank interest rate is equal to the policy target, Equation (7), as it is expected when a symmetric corridor approach is put into place. Indeed, under this formalisation, this equality occurs only when ϵ_{on} is equal to zero, that is when the interbank market is in equilibrium before any price-adjustment. In reality, the central bank intervenes daily with open market operations in order to meet the target; however, for simplicity reasons, it is assumed that the 'symmetric corridor makes it possible to avoid the need to adjust liquidity conditions' (Bindseil, 2004) via quantity buffers.

Since the interest rate in the term segment did not necessarily fall inside the corridor in pre-crisis periods, not being among the targets of the monetary authority, it will be analysed in the baseline scenario with arbitrary values exogenously assigned to η_1 and η_2 . These values will be changed in one of the experiments such that η_1 becomes equal to the floor rate, and η_2 to the width of the corridor ($\bar{i}_{cb}^l - \bar{i}_{cb}^d$), in order to resemble the change in monetary policy happened in light of the financial crisis, when also long-term rates became objectives of the central bank in its quantitative easing practices.

Second, the two rates are dependent on ϵ_{on} and ϵ_{term} , expressed as measures for net demands on the interbank market, and being positive in case of excess demand and negative in case of excess supply. As a consequence, they will adjust such that i_{ib}^{on} , or i_{ib}^{term} , will increase, up to \bar{i}_{cb}^l for the overnight segment, in conditions of excess demand, and will decrease, up to \bar{i}_{cb}^d for the overnight rate, in conditions of excess supply. In this regard, to be sure that these changes of interest rates will lead to the equilibrium condition of equality between demand and supply, interbank demand and interbank supply functions must be *well-behaved*. In other words, the first derivative of IB^D with respect to both interest rates has to be negative; and that the first derivative of IB^S with respect to both interest rates must be positive, as showed by Equations (h)–(s) in Appendix C.

3.3.3 | Credit market

The setting of the credit market and of banks' liquidity preferences will be treated in a very simple fashion. Both banks can choose between short-term loans and bills.

Let us define the matrices for the two banks as follows.

$$\begin{bmatrix} L_f \\ B_j \end{bmatrix} = \begin{bmatrix} \bar{\lambda}_{10} \\ \bar{\lambda}_{20} \end{bmatrix} F_j + \begin{bmatrix} \bar{\lambda}_{11} & -\bar{\lambda}_{12} \\ -\bar{\lambda}_{21} & \bar{\lambda}_{22} \end{bmatrix} \begin{bmatrix} i_f^l \\ i_b \end{bmatrix} F_j \quad (d)$$

$$\begin{bmatrix} L_h \\ B_k \end{bmatrix} = \begin{bmatrix} \bar{\beta}_{10} \\ \bar{\beta}_{20} \end{bmatrix} F_k + \begin{bmatrix} \bar{\beta}_{11} & -\bar{\beta}_{12} \\ -\bar{\beta}_{21} & \bar{\beta}_{22} \end{bmatrix} \begin{bmatrix} i_h^l \\ i_b \end{bmatrix} F_k \quad (e)$$

Bank j 's loans to firms and bank k 's loans to households can be expressed as in Equations (35) and (36), by following Le Heron and Mouakil (2008) and Le Heron (2011). Moreover, F_j and F_k represent the two banks external finance, interpreted as the main source of funds for firms and households.

$$L_f = [\bar{\lambda}_{10} + \bar{\lambda}_{11}i_f^l - \bar{\lambda}_{12}i_b]F_j \quad (35)$$

$$L_h = [\bar{\beta}_{10} + \bar{\beta}_{11}i_h^l - \bar{\beta}_{12}i_b]F_k \quad (36)$$

External finance is defined according to Dafermos (2012), by including a measure for credit rationing for both sectors (CR_f , CR_h), dependent on the perceived degree of uncertainty¹⁸ and the last period loans to capital ratio for the firms' sector and loans to net wealth ratio for the households' one. The variables indicating firms' demand for funds (L_f^D) and households' demand for loans (L_h^D) are defined in Appendix A.

$$F_j = F_{j(-1)} + (L_f^D - F_{j(-1)})(1 - CR_f) \quad (37)$$

$$CR_f = \bar{\omega}_1 \overline{PDU} + \bar{\omega}_2 \frac{L_{f(-1)}}{K_{(-1)}} \quad (38)$$

$$F_k = F_{k(-1)} + (L_h^D - F_{k(-1)})(1 - CR_h) \quad (39)$$

$$CR_h = \bar{\omega}_1 \overline{PDU} + \bar{\omega}_2 \frac{L_{h(-1)}}{V_{h(-1)}} \quad (40)$$

¹⁸In line with the Post-Keynesian literature, although simplified in the context of this paper, the existence of a 'group of borrowers who are refused credit' (Wolfson, 1996) is determined by agents' *fundamental uncertainty* about the future course of events.

Banks' demand for short-term government securities, held as liquidity buffer, can be determined residually in both cases.

$$B_j = F_j - L_f \quad (41)$$

$$B_k = F_k - L_h \quad (42)$$

In this model, the demand for government bonds is assumed to act as a buffer variable in bank j 's capital account, formalised as in Equation (43-vi).

$$B_j^{lr} = B_{(-1)}^{lr} + P_{bj}^u + \Delta D_f + \Delta Ovd_j + \Delta IB_{on} + \Delta IB_{term} + \Delta R_{cb}^l - \Delta B_j - \Delta L_f - \Delta HPM_j \quad (43-vi)$$

As regards the determination of interest rates in the credit market, the two banks have to set the interest rates on households' and firms' loans and deposits. It is assumed that both banks decide these rates based on their funding costs, similar to Schasfoort et al. (2017). Bank k 's funding cost is represented only by the central bank's target interest rate to which loans and deposits rates are anchored. For bank j , instead, funding costs (f_{c_j}) are defined in Equation (44), and are expressed as the average between the targeted interest rate i_{cb}^l , the costs faced on the interbank market i_{ib}^* , whose value depends on θ and $L_b W$, and the cost of accessing the central bank's lending facility when needed, i_{cb}^{l*} .

$$f_{c_j} = \frac{i_{cb}^l + i_{ib}^* + i_{cb}^{l*}}{\zeta} \quad (44)$$

$$i_{ib}^* = \begin{cases} i_{ib}^{on} & \text{if } \theta = L_b W = 1 \text{ or } 0 < \theta < 1 \text{ and } L_b W = 1 \\ & \text{or } \theta = 1 \text{ and } 0 < L_b W < 1 \\ i_{ib}^{term} & \text{if } \theta = L_b W = 0 \text{ or } 0 < \theta < 1 \text{ and } L_b W = 0 \\ & \text{or } \theta = 0 \text{ and } 0 < L_b W < 1 \\ \frac{(i_{ib}^{on} + i_{ib}^{term})}{2} & \text{if } 0 < \theta < 1 \text{ and } 0 < L_b W < 1 \\ 0 & \text{otherwise} \end{cases} \quad (45)$$

$$i_{cb}^{l*} = \begin{cases} \bar{i}_{cb}^l & \text{if } R_{cb}^l \neq 0 \\ 0 & \text{otherwise} \end{cases} \quad (46)$$

$$\zeta = \begin{cases} 2 & \text{if } i_{ib}^* = 0 \text{ and } i_{cb}^{l*} \neq 0 \text{ or } i_{ib}^* \neq 0 \text{ and } i_{cb}^{l*} = 0 \\ 3 & \text{if } i_{ib}^* = i_{cb}^{l*} \neq 0 \end{cases} \quad (47)$$

On these premises, the interest rates determination is simply based on constant *mark-up* and *mark-down* rules following Le Heron and Mouakil (2008), Equations (48)–(51), as advocated by *horizontalist* Post-Keynesians.

$$i_h^l = f_{c_j} + \bar{\chi}_1 \quad (48)$$

$$i_h^d = f_{c_j} - \overline{\chi_2} \quad (49)$$

$$i_f^l = i_{cb}^t + \overline{\chi_1} \quad (50)$$

$$i_f^d = i_{cb}^t - \overline{\chi_2} \quad (51)$$

$$P_{bj} \equiv i_b B_{j(-1)} + i_b^{lr} B_{(-1)}^{lr} + i_{f(-1)}^l L_{f(-1)} - i_{f(-1)}^d D_{f(-1)} - i_{cb}^{l} R_{cb(-1)}^l - i_{ib(-1)}^{on} IB_{on(-1)} - i_{ib(-1)}^{term} IB_{term(-1)} \quad (52-v)$$

$$P_{bk} \equiv i_{cb}^{d} R_{cb(-1)}^d + i_{h(-1)}^l L_{h(-1)} + i_{ib(-1)}^{on} IB_{on(-1)} + i_{ib(-1)}^{term} IB_{term(-1)} - i_{h(-1)}^d D_{h(-1)} \quad (53-vii)$$

$$Div_{bj} = (1 - \bar{s}_j) P_{bj(-1)} \quad (54)$$

$$Div_{bk} = (1 - \bar{s}_k) P_{bk(-1)} \quad (55)$$

$$P_{bj}^u \equiv P_{bj} - Div_{bj} \quad (56-xii)$$

$$P_{bk}^u \equiv P_{bk} - Div_{bk} \quad (57-xiii)$$

The last six equations define, respectively, total banks' profits (Equations 52-v and 53-vii), dividends distributed to the household sector (Equations 54 and 55), and retained earnings of the banking sector (Equations 56-xii and 57-xiii).

$$V_{bj} = V_{bj(-1)} + \Delta L_f + \Delta B_j + \Delta B_j^{lr} + \Delta HPM_j - \Delta D_f - \Delta IB_{on} - \Delta IB_{term} - \Delta Ovd_j - \Delta R_{cb}^l \quad (58)$$

In conclusion, Equation (58) characterises bank j 's net worth via the change in stocks derived from the balance sheet matrix.

The model is closed with 80 unknowns in 80 equations. The remaining 22 equations regarding the behaviour of the other agents in the model, as well as the redundant equation, are formalised in Appendix A.

4 | SIMULATION AND EXPERIMENTS

As a result of the complexity of the dynamic model presented in the previous section, simulations and experiments have been conducted via numerical solutions instead of analytical ones. The methodology used in this study combines the procedures explained by Caiani et al. (2016) and

Godley and Lavoie (2006), both of them involving the following steps: (i) identifying the steady-state (SS) solution of the system, (ii) solving the model for the initial values of stocks and flows, and (iii) making some experiments by altering the values of the exogenous variables and of the economically significant parameters.

Finding the steady-state solution and the initial values of stocks and flows required focusing only on the macro core of the model. To do so, some simplifying assumptions and conditions had to be imposed.

First, the size of the system has been drastically reduced from 80 unknowns in 80 equations into 40 unknowns in 40 equations. Second, all the variables defined through piece-wise functions have been set exogenously as in Caiani et al. (2016), in order to neglect the nonlinearity of the system. Third, the following assumptions have been made: (i) market clearing for the interbank sector, both in the overnight and in the term segment ($IB_{on}^D = IB_{on}^S$; $IB_{term}^D = IB_{term}^S$); (ii) the supply function for interbank funds has been ignored, as well as bank k 's willingness to lend overnight ($L_b W$); (iii) the final stocks of interbank loans, both overnight and term, have been considered to be equal to the demanded quantities as a consequence of the market clearing condition ($IB_{on} = IB_{on}^D$; $IB_{term} = IB_{term}^D$); (iv) the overnight interbank interest rate has been assumed to be equal to the central bank's policy target rate ($i_{ib}^{on} = i_{cb}^t$); (v) all the interest rates of the model have been set exogenously, as well as bank j 's willingness to borrow overnight (θ), the variables defining credit rationing in the credit market (CR_f and CR_h) and firms' capital stock (K); (vi) the equation defining government expenditure (G) has been changed with the one deriving from the SS condition of balanced government budget¹⁹; and (vii) households' expected disposable income has been considered equal to the effective disposable income ($Y_d^a = Y_d$).

Last, the values of the parameters and of the exogenous variables have been assigned in accordance to existing literature, Table 3 in the Appendix B, such as Caiani et al. (2016), Le Heron and Mouakil (2008) and Popoyan et al. (2017).

At this point, following the methodology adopted by Caiani et al. (2016), this *simplified* version of the model has been constrained to a real steady state (g_{ss}). This method creates a system where 'real variables are constant and nominal variables grow at a constant rate' (Veneziani & Zamparelli, 2018), by imposing two transformations to flows and lagged endogenous variables: for any generic endogenous variable X , it must hold that $X_{(-1)} = X(\frac{1}{(1+g_{ss})})$, and that $\Delta X = X(\frac{g_{ss}}{(1+g_{ss})})$.

The adoption of this approach has allowed the computation of the initial values of stocks and flows, summarised in Tables 5 and 6 in Appendix B, used to anchor the values of the lagged endogenous variables in the simulations of the *complete* model, which have been conducted over maximum 38 periods to guarantee the convergence of the system.

4.1 | Baseline scenario

Figure 2 depicts the dynamics of the baseline scenario with respect to the variables concerning the interbank market, being the main focus of this analysis.

As expected, the evolution of the stocks of interbank loans (Figure 2a) is strongly related to the dynamics of banks' willingness to borrow (θ) and lend overnight ($L_b W$) (Figure 2e). Indeed,

¹⁹By imposing the equality between G and T , expressed via Equation (4) in Appendix A, and substituting for W , Equation (17) in Appendix A, the resulting SS expression for government expenditure is $G = \frac{(\bar{r}Y)}{(1+\bar{p})}$.

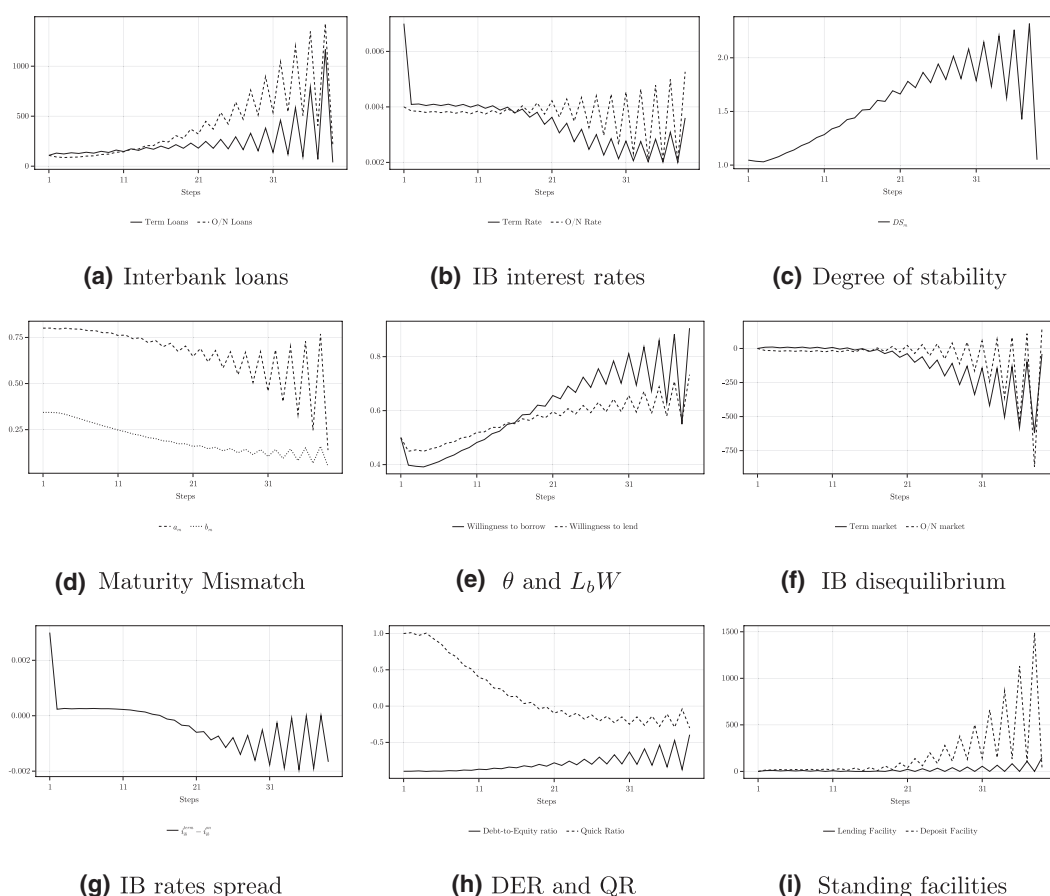


FIGURE 2 Dynamics of the Baseline Scenario

overnight loans appear to be lower than the term ones for a short period of time, during which both θ and $L_b W$ experience a slight U-shaped dynamic. After some periods, overnight loans outperform term exchanges given (i) a high degree of stability of the borrowing bank (see Figure 2c), and (ii) a decreasing quick ratio (see Figure 2h) which makes the lending bank more willing to supply loans entailing more refinancing legs. The levels of b_m and a_m , which represent, respectively, the proportion of required stable funds over total assets and the proportion of available stable funds over total liabilities, show the presence of a constantly low maturity mismatch in bank j 's balance sheet, captured by degree of stability depicted in Figure 2c. About the interest rates, Figure 2b captures the dynamics of the interbank interest rates, and Figure 2g reproduces the interbank spread, which, as a consequence of how the model has been constructed, depends on interbank market disequilibrium dynamics, captured by ϵ_{on} and ϵ_{term} in Figure 2f). Both interbank rates oscillate around the central bank's target rate until step 20. After this period, (i) the term rate decreases toward the floor of the central bank's corridor as a result of a higher and increasing excess supply in the term segment and (ii) the overnight rate experiences a higher volatility triggered by the increasing variability of overnight interbank disequilibrium dynamics. Excess supply in both segments is deposited at the central bank (see Figure 2i).

The oscillatory trend revealed by the dynamics of the baseline scenario are derived from the combination of (i) the high complexity of the model and (ii) the very short simulation period

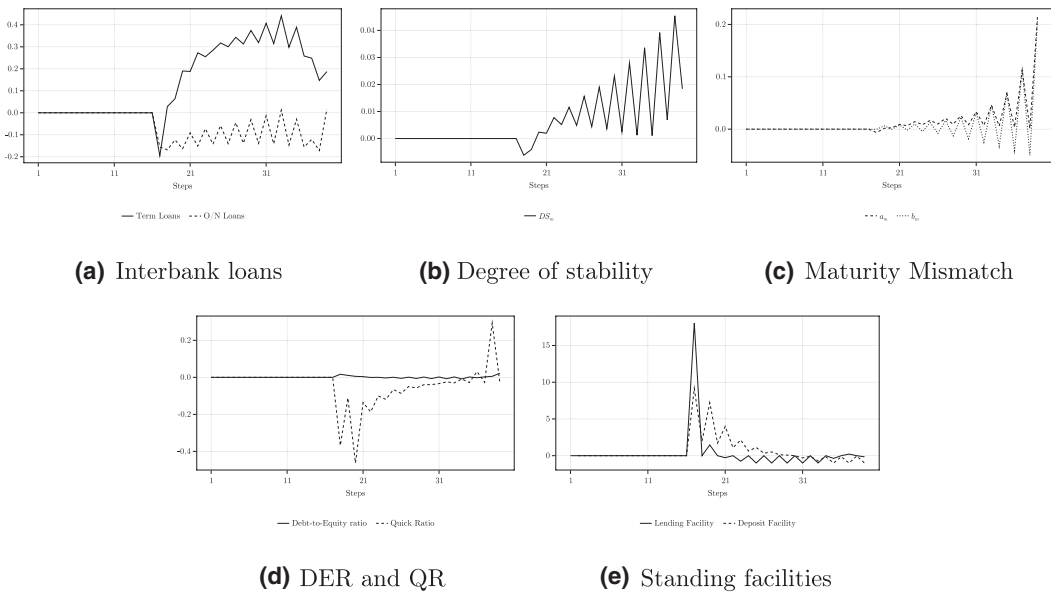


FIGURE 3 Effects of an increase in the perceived degree of uncertainty (*PDU*)—growth rates. The very high volatility of the trends impairs the ability to provide a clear comparison by simply plotting the evolution of the dynamics. For this reason, Figures 3, 5, 7, 9 and 10 depict the performance of the economy under each scenario in terms of growth rates relative to the baseline case

considered. At this stage of the analysis, the length of the simulations can not be increased since the convergence of the system would not be ensured for longer periods. This issue might fade away once a proper calibration of the parameters is put into place, which is left for further research.

4.2 | Perceived uncertainty shock

As a first experiment, the simulated economy has been hit by an uncertainty shock. In period 15, the level of the exogenous variable *PDU* has been drastically increased from 0.1 to 0.6, whose effects to the dynamics of interbank interactions are captured in Figures 3 and 4. After the shock, the rate of growth of volumes exchanged in the term (overnight) interbank market (Figure 3a) increase (decrease) relative to the baseline dynamics. The immediate downward pick of the funds exchanged in both segments is followed by a higher recourse to both standing facilities. While bank *j* asks the central bank for the term funds it is not able to acquire on the interbank market, the lending bank deposits the excess overnight funds it would be able to lend out on the interbank market.

The effects of higher uncertainty have a trivial impact on the degree of stability of bank *j* (Figure 3b): DS_m grows at lower rates immediately after the shock, triggered by the dynamics of term funds which influence the amount of the borrowing bank's available stable funds (a_m). Despite an increase in the perceived degree of uncertainty leads to a decline in bank *j*'s degree of stability, its impact is *temporary* since the higher volumes exchanged on the term segment over time lead to a growing degree of stability over the long-run.

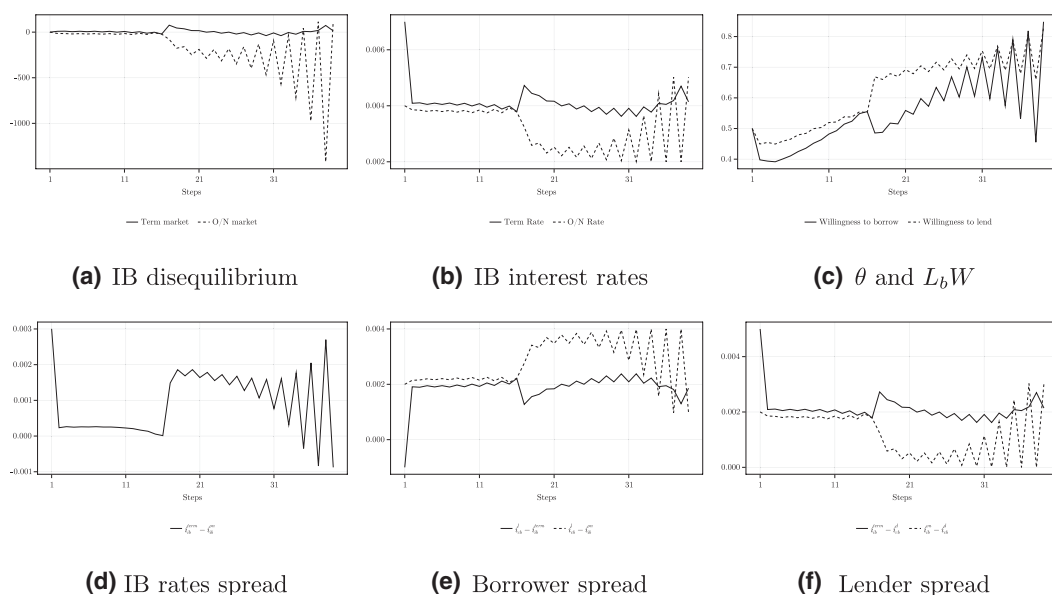


FIGURE 4 Effects of an increase in the perceived degree of uncertainty (*PDU*)—dynamics

From the perspective of the lending bank, the impact of the uncertainty shock on its willingness to lend overnight is strong and is influenced by the lower ability of the borrowing bank to repay its short-run obligations, suggested by the decreasing quick ratio depicted in Figure 3d. These opposite dynamics impacted the evolution of the stocks of interbank loans, strongly influenced by the path followed by excess demand for term interbank loans and excess supply for overnight interbank loans, which cause interbank exchanges to follow the term supply, on the one hand, and the overnight demand, on the other.

As a result of the increase in *PDU*, θ and L_bW (Figure 4c) take divergent paths and the term segment disequilibrium appears to be significantly lower and to stabilise around zero, after a slight excess demand pick immediately after the shock (Figure 4a).

As a consequence of the price clearing mechanism in the interbank market (Figure 4b), the interest rates spread shrinks, with the term interbank rate oscillating around the targeted interest rate, and the overnight one around the floor.

Overall, in a situation of higher perceived uncertainty in the interbank market, the higher willingness of the lending bank to provide overnight funds has not discouraged a stronger growth path of term interbank exchanges, making the borrowing bank's degree of stability rise and leading to a lower dynamic of the interbank interest rate spread (Figure 4d).

Moreover, a higher term interest rate seems not to discourage bank *j*'s preference for term interbank contracts. This aspect is probably linked to the decreasing maturity mismatch emerging from the rise in the degree of stability, whose effects are predominant in determining the final volumes exchanged in the postulated segments of the interbank market.

About the credit market, the rise in uncertainty had a null impact on the interest rate charged to households. This is due to the fact that bank *k*'s decisions about credit market rates depend on the target policy rate which has not changed in this scenario. On the contrary, the effects of an increase in *PDU* on bank *j*'s funding costs and firms' loans rate appear less straightforward: first, the credit market rate temporarily decreases, probably because the decline in overnight funding costs neutralises the higher term interbank costs; second, as the growth rate of overnight

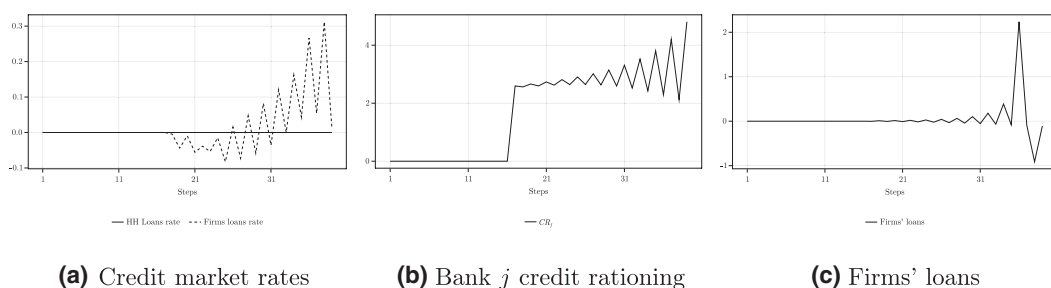


FIGURE 5 Credit market after a PDU shock—growth rates

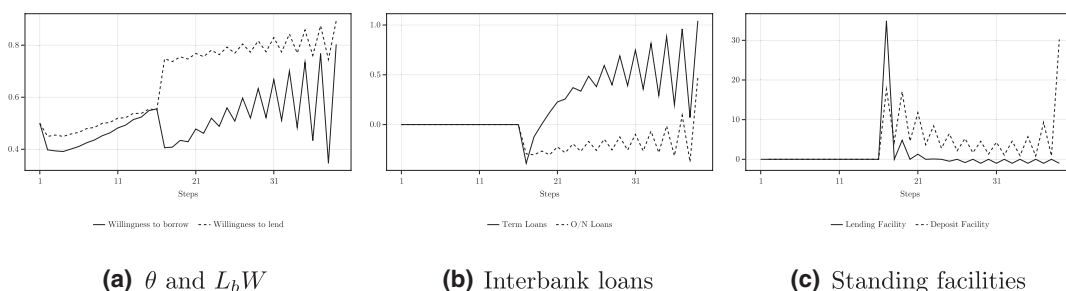


FIGURE 6 Effects of a maximum degree of perceived uncertainty

loans decreases, the impact of the overnight rate on bank j 's funding costs becomes negligible, leading to an increase in firms' loans rate. Overall, the trivial influence of uncertainty on credit market volumes manifest itself over the long-run (see Figure 5c), despite the rise of firms' credit rationing is immediate.

As a further exercise, the system has been shocked by a level of maximum uncertainty, with PDU set equal to one. It may be noticed from Figure 6 that only at this highest level of uncertainty interbank frictions in the market, triggered by banks' maturity preferences, lead to a very high recourse by the lending bank to the central bank's deposit facility. The amount of interbank funds deposited at the central bank is now enormous, compared to the previous scenario. Moreover, the higher the increase in uncertainty, the lower the rise of term interbank exchanges and the higher the drop in overnight volumes. This might suggest that an increase of the stress perceived in the economy (i) leads to an overall reduction of the volumes exchanged in the interbank market and (ii) encourages the lending bank to hoard liquidity at the central bank, in accordance to what happened during the last financial crisis.

4.3 | Contractionary monetary policy

Another experiment conducted in this analysis regards the level of the central bank's policy rates. Figures 7 and 8 depict the evolution of the analysed economy after a rise of the lending rate from 0.006 to 0.016, and of the deposit one from 0.002 to 0.012. The width of the corridor has been held constant at 0.004.

Interbank volumes in the term segment appear more volatile towards the end of the simulation period, though the exchanges in this market do not suffer from a substantial divergence from

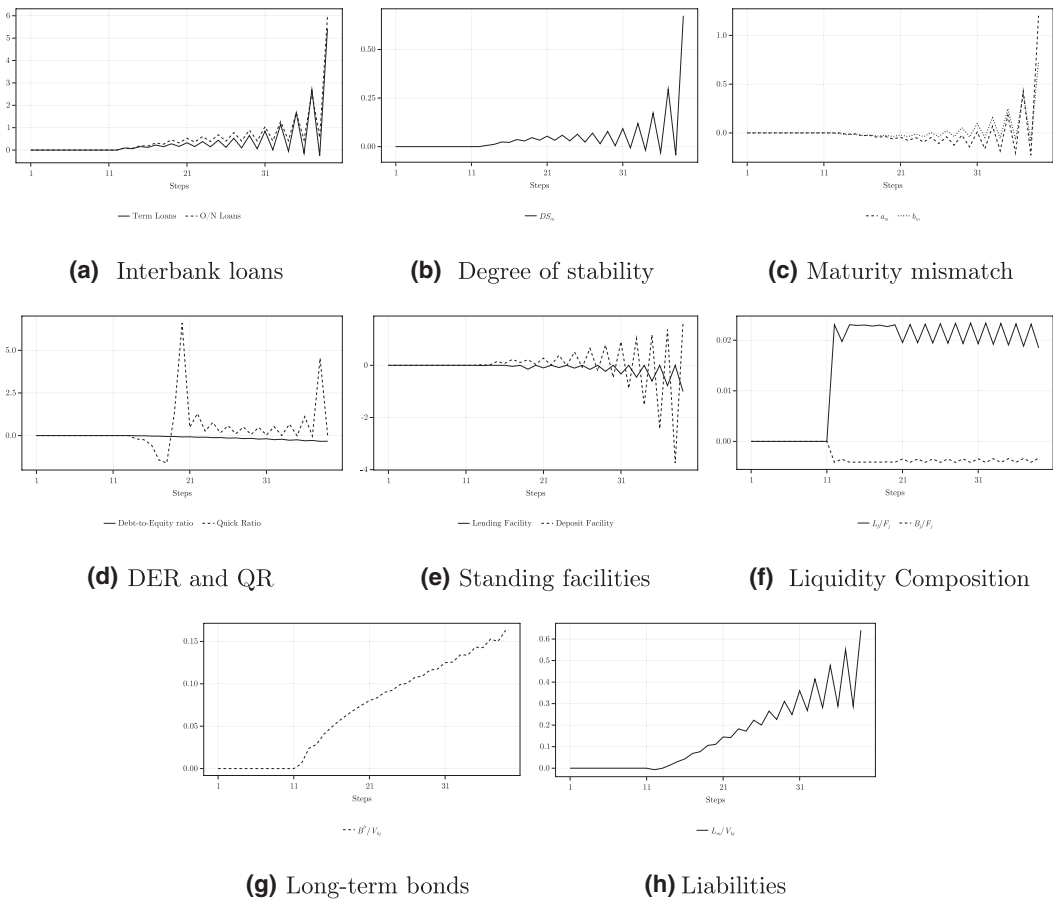


FIGURE 7 Effects of a monetary policy shock—growth rates

the baseline levels. Instead, both banks seem to prefer to borrow and lend overnight (Figure 8c) leading to higher levels of overnight funds. A higher degree of stability encourages the borrowing bank to demand a less amount of term funds. From the lending bank's perspective, its increasing willingness to lend overnight funds seem not to derive from a deterioration of the ability of bank j to repay its short-run obligation (see Figure 7d) but instead from the impact the decreasing lender rate spread has on $L_b W$ (Figure 8f). After the shock, the levels of the term excess supply increase more rapidly than the ones of the baseline scenario, leading to a decreasing interbank interest rate spread. The degree of stability increases after the economy is hit by a contractionary monetary policy shock. Figure 7f–h shows the changes in the composition of bank j 's liquidity composition, long-term assets and liabilities. The higher central bank's corridor triggers the bills interest rate from 0.004 to 0.014, and the loans interest rate at around 0.016. Looking at the liquidity composition, it appears that this interest rate rise strongly encouraged bank j to provide more loans to firms and to engage less in the purchase of government bills. The increase in bank j 's degree of stability seems to be highly influenced by the rise in total liabilities, expressed in Figure 7h as a ratio over the bank's net worth (V_{bj}).

The dynamic process that occurs between a contractionary monetary policy and the credit market is illustrated in Figure 9. The central bank's rates hike causes an increase of the rates of interest in the credit market (Figure 9a). This increase of interest rates should lead to a

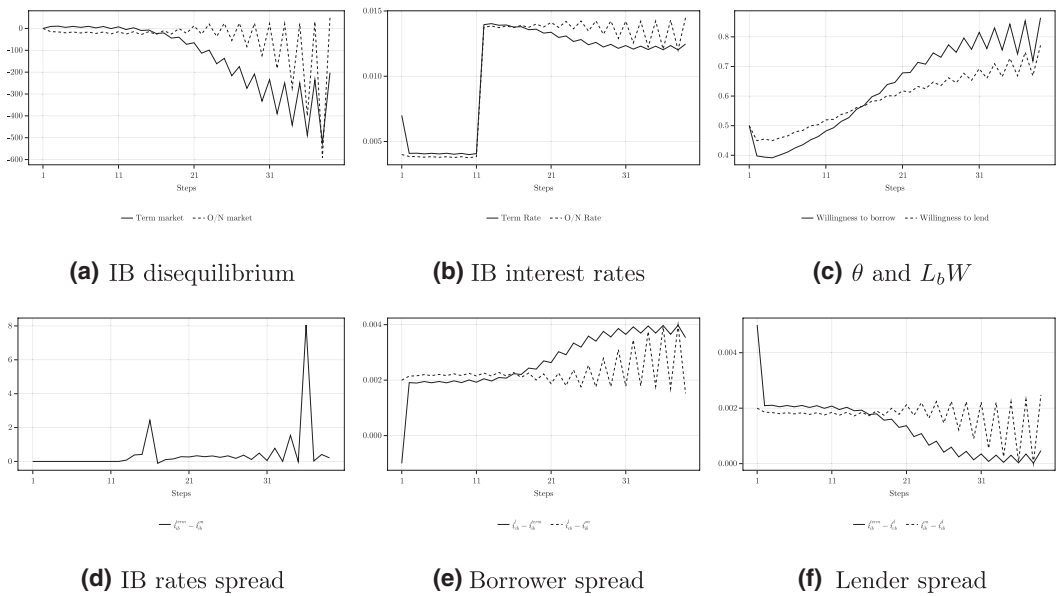


FIGURE 8 Effects of a monetary policy shock—dynamics

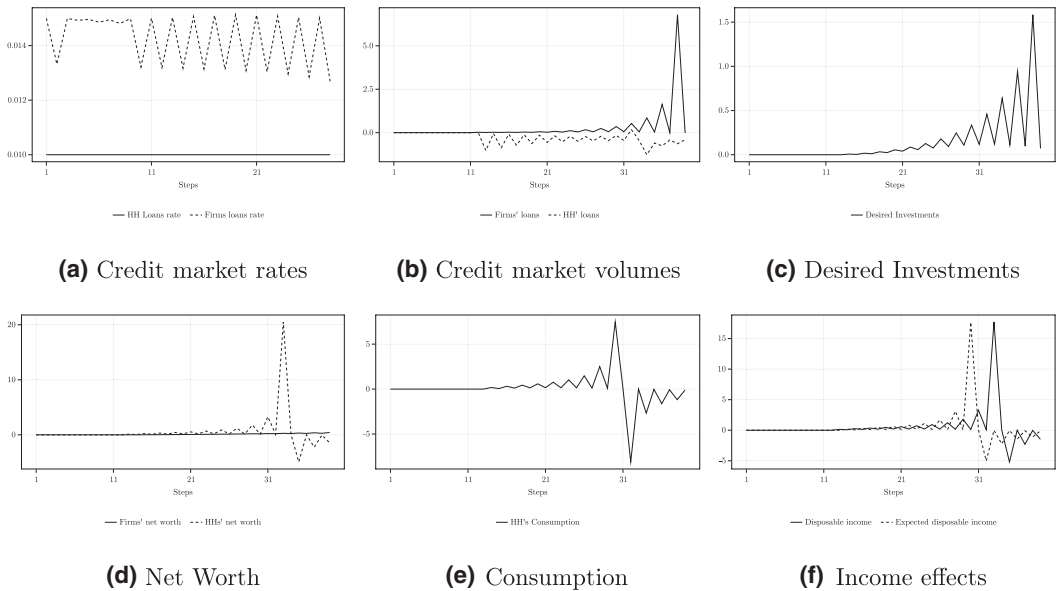


FIGURE 9 Credit market after a monetary policy shock—growth rates

contraction of loans provided to the agents in the real economy, according to the dictates of the monetary policy transmission mechanism. The rise of the central bank's policy rates should lead to a reduction of lending volumes through (i) an upward pressure on banks' funding costs (bank lending channel); (ii) the effect of short-term interest rates on agents' net worth (balance sheet channel); and (iii) the impact of higher loans rates of interest on investments (investment channel).

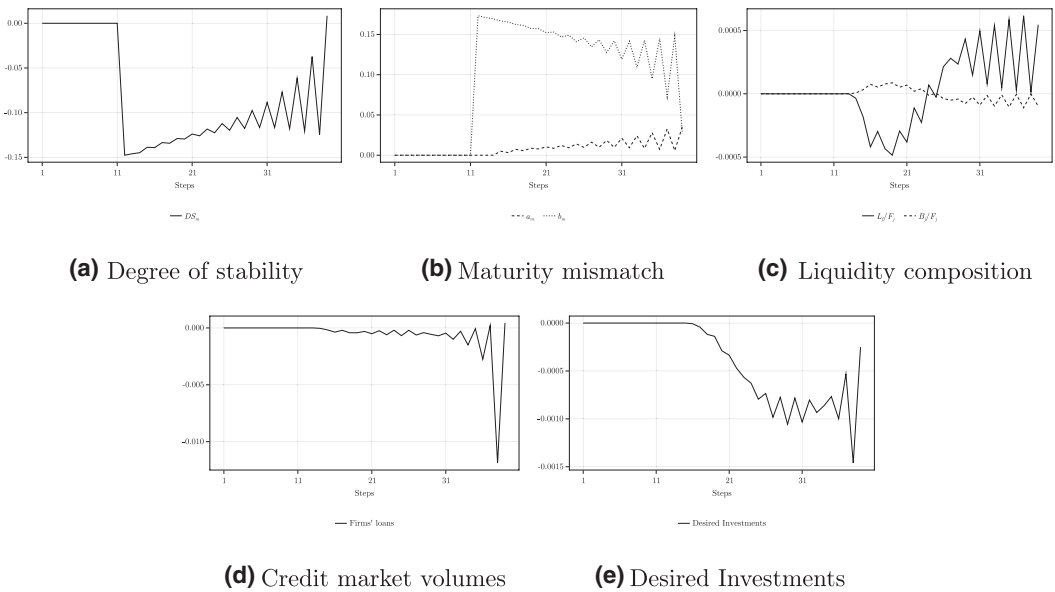


FIGURE 10 Effects of a lower degree of liquidity of bank j 's asset side—growth rates

The volumes lent out to households in the form of loans appear to grow at a lower rate relative to the baseline scenario. However, consumption trends appear not to be influenced by households' ability to raise funds on the credit market. Indeed, consumption expenditures become less attractive only over the long-run as the result of wealth and income effects (Figure 9f), which follow the downward trend of households' net worth (Figure 9d). Therefore, a lower credit volumes growth rate in the households sector could have been triggered by the higher funding costs bank k suffers after the increase in the corridor rates (bank lending channel).

Firms' loans seem to be unaffected by the interest rate hike, and they even increase towards the end of the simulation period, as well as desired investment (see Figure 9b,c). Along these lines, firms' net worth does not react to the monetary policy shock. These effects on the firm sector are the result of an inefficient monetary policy transmission mechanism along all its channels.²⁰ From the demand side, there is no impact of higher costs of financing on investments acting through a lower desire for capital stock accumulation. This might be due to an exogenous growth rate of capital which makes investments disentangled both from firms' capacity utilisation and from the interest rate on loans. However, it seems to be in line with the heterodox criticism to the mainstream notion of a decreasing marginal productivity of capital and to the Post-Keynesian view of firms' demand for credit and investments as not affected by interest rates (Deleidi, 2018). From the supply side, a potential explanation lies in the interaction between banks' funding decisions and liquidity preferences. Not only a higher credit market rate incentives bank j to provide more loans to corporations instead of investing in government bills (see Figure 7f), but also a constantly high degree of stability might have offset any potential discouraging effect of higher funding costs.

Therefore, the maturity composition of the bank's funding sources might play a relevant role in this setting.

²⁰Neither the cost channel nor the consequences on inflation can be analysed in this context because the price level is set exogenously.

To prove this, an additional experiment has been conducted with the aim of inducing an endogenous shock to bank j 's maturity mismatch, being the main driver of funding decisions within this context. Maintaining the corridor rates at the baseline scenario levels, suppose that bank j now provides only long-term loans to the firm sector. Given the dictates of the NSFR, the macro prudential regulation authority assigns an *RSF* risk factor of to loans whose duration is greater or equal than one year.²¹ Figure 10 depicts what happens in this scenario. Given a very high maturity mismatch in bank j 's balance sheet, since the amount of required stable funds is now higher than the level of available stable funds (Figure 10b), the degree of stability sharply decreases by the same amount. The alteration of the liquidity conditions of bank j makes firms credit availability decrease, as well as desired investments (Figure 10d,e). In this case, the higher bank j 's preference for firms loans over the long-run is not transmitted to the credit market as long as the degree of stability is not recovered, i.e. funding decisions can be identified as an endogenous source of financial market imbalances affecting credit provision.

In the context of the theoretical debate within the Post-Keynesian literature about central banking, these results might be interpreted either as (i) a confirmation of the *horizontalist* concern that 'if both money and rates were in fact really endogenous, monetary policy could have no effect on the economy' (Moore, 1995), or as (ii) the *structuralist* emphasis that the availability of credit is subject only to 'endogenous pressures within financial markets' and that 'central bank interventions to control the growth rate of money and credit are not nearly as potent a tool as they are assumed to be in the mainstream literature' (Pollin, 1991).

5 | CONCLUSIONS

The present paper has been intended as a first step to build a more complex financial system within a SFC framework in the attempts (i) to model the second causal link of endogenous monetary theory, from deposits to reserves; and (ii) to incorporate banks' debt structure decisions in terms of maturities as determinants for bilateral interbank transactions.

Starting from the design of a payment system within a monetised production economy, two banking institutions engage in *reserve management strategies* for settlement purposes in two segments of the postulated interbank market: overnight and term. The unique feature of this model is that the two banks' decisions about the maturity of the demanded and supplied interbank contracts depend on the degree of maturity transformation, or *degree of stability*, to account for banks' funding liquidity risk or risk of rollover.

The simulations of the model have produced some interesting results. Alterations of the borrowing bank's maturity mismatch led the volumes of the overnight segment to grow less than the ones exchanged in the term market, suggesting the need of a well-functioning term segment of the interbank market when considerations about the risk of rollover are not neglected. Moreover, in the event of increasing tensions in the market, (i) the growth rates of the funds exchanged in the interbank market shrinks, (ii) the lending bank hoards higher amounts of liquidity at the central bank's deposit facility and (iii) the borrowing bank starts accessing the lending facility for the term funds it is not able to raise on the interbank market, in line with the recent economic downturn. The potential migration of banks from the term to the overnight segment, as advocated by Acharya and Skeie (2011), has not yet emerged in the present analysis, since the

²¹The exogenous parameter m_1 has been increased from 0.1 to 0.65.

borrowing bank has always had a very high degree of stability. Moreover, the specification of interbank market volumes as strictly dependent on excess supply and excess demand dynamics might not allow to inquire into any potential migration.

A contractionary monetary policy shock has produced non-trivial results. The inefficiency of the monetary policy transmission mechanism on the firm sector might be interpreted in light of the Post-Keynesian dictates: when money is endogenous, central bank interventions lose their power. Therefore, when banking decisions are strictly dependent on funding risk, not only the real economy is more resilient to exogenous shocks, but also macro prudential regulation interventions might be more effective.

In conclusion, banks' structure of financing may disclose the drivers of debt-financing contraction, which cannot be exhaustively explained by higher credit risk; and may reveal a potential threat to the desirable balance between discipline and elasticity, both required for a well-functioning money market and for detecting potential endogenous tensions able to alter the provision of loans in the credit market.

In the attempt to overcome some limitations of this analysis, further developments of this work should mainly focus on (i) a proper calibration of parameters based on real-world data, (ii) endogenous consumption goods prices to evaluate policy experiments in terms of inflation, (iii) the introduction of deposit flows arising from households' consumption expenditures, (iv) including National Central Banks to be more in line with the Eurozone real practices, and (v) extending the analysis to an Agent-Based Stock-Flow consistent (AB-SFC) framework to allow for agents' heterogeneity and more complex interactions.

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