

Interbank Market and Funding Liquidity Risk in a Stock-Flow Consistent Model

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Abstract

The economic downturn following the collapse of Lehman Brothers has shown how erroneous it would be to separate the well-being of current capitalism from the well-functioning of the two interdependent roles played by the banking system. Indeed, the ability of banks to both *create* money in the form of deposits, and to *smooth* payment liquidity shocks can not be neglected. In this context, the aim of the present model is two-fold. First, to extend the current Stock-Flow Consistent framework including bank-to-bank relations to capture both potential intra-sectoral flows, and the second causal link of endogenous monetary theory, from changes in deposits to changes in reserves. Second, to build a more complex banking system including *debt maturity structure* decisions and *reserve management strategies*, with the aim of analyzing the impact of funding liquidity risk on the performance of the postulated interbank market. Starting from the functioning of a payment system within an overdraft economy, two banks can interact in two segments of the unsecured interbank market: the overnight and the term one. The main feature of this model is the introduction of a measure for maturity mismatch and funding liquidity risk according to which the borrowing bank can choose the demanded duration of interbank loans. The central bank is modelled in both its accommodating and disciplinary roles, in case interbank lending comes to a standstill. The main results of the simulations are: i) interbank volumes seem to be highly dependent on the maturity composition of the two banks' balance sheets; ii) as the stress perceived in the interbank market increases, banks' maturity preferences lead the interbank market rates spread to its highest possible levels; iii) the constant excessive maturity mismatch leads the volumes of the overnight segment to be lower with respect to the term one, suggesting the importance of the latter when considering funding liquidity risk.

Keywords: Monetary Policy, Interbank Market, Rollover Risk, Stock-Flow Consistent models

JEL Codes: E5, E12, E42, G01, G11, G18, G21, G32

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1 Introduction

Since the last financial crisis, interbank market dynamics have gathered greater attention among researchers. In light of what happened after the collapse of Lehman Brothers, impaired 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; 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 practises 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 emphasizing 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"¹, 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, i.e. 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 intra-sectoral flows considerations, and ii) the lack of a comprehensive behaviour of the banking system with respect to portfolio choices.

¹Gnos and Rochon (2011), page 110.

Based on real-world banking practises, 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"². 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"³, 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 light of this, when dealing with banks' portfolio choices, their *debt maturity structure* decisions should not be neglected. These ones are the key to analyze 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 liquidity⁴. On the other, when maturity mismatch practises 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 debts⁵. 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 practises 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 practises, which impact their ability to expand credit when needed and the effectiveness of the central bank's operations, the aim of this model is two-fold: i) to extend the current structure of SFC modelling by including simple bank-to-bank relations to

²Dymski (1988), page 519.

³Lavoie (2009), page 61.

⁴Banks create liquidity by transforming illiquid or long-term assets, like long-term loans or mortgages, into short-term liabilities, such as sight deposits.

⁵In 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.

capture intra-sectoral flows, and ii) to analyze 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 introduces the general characteristics of the model, matrices, variables, the accounting identities and the institutional context. The next three subsections describe the behaviour of the agents in the model, 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 center of their analysis. Post-Keynesians, indeed, describe capitalism as a monetized 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"⁶. 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"⁷, 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

⁶Gnos and Rochon (2011), page 100.

⁷Rochon and Rossi (2007) page 544.

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 may be detected in the high level of aggregation these models have by construction, which confines the analysis to inter-sectoral flows while leaving aside intra-sectoral ones. As 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 analyze 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 the banking one, are treated in aggregate terms.

Despite the fact that these hybrid AB-SFC models formalize interbank relations in the attempt to study either the central bank's transmission mechanism or bank's expectations, the interbank market has been still "modelled in a fairly simple fashion"⁸, to the detriment of realism.

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 generalize 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 practises might trigger banks' refinancing troubles, which could be analyzed by taking into account their funding liquidity risk or risk of rollover.

As an evidence arose from the recent financial crisis, 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 loans⁹

⁸Reissl (2018), page 19.

⁹By engaging in term interbank contracts, borrowing banks can re-access the market to raise

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 and Skeie, 2011).

To conclude, while the most recent hybrid AB-SFC models still highly simplify banks' characteristics, not taking into account possible banks' refinance problems and their potential inability to renew flows of past debts, which could impair intra-banks flows; pure SFC frameworks with a more realistic representation of the banking system still ignore banks' liability side and the relevance of funding costs on interest rates determination on the credit market, which can be captured only by modelling interbank market interactions.

3 The model

A Stock-Flow Consistent 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. Finally, it will be necessary to build the whole model by defining each unknown either through a behavioral 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 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

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.

reserves that they are legally required to hold"¹⁰, 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 and Rossi, 2011), via marginal refinancing operations and accommodating advances to banks in reserve shortage; but also, it 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"¹¹.

In the context of this analysis, the central bank's balance sheet is almost "perfectly lean"¹², 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, four elements will be considered. First, main refinancing operations (*MRO*), an active monetary policy tool for structural liquidity provision determined at the initiative of the central bank. Second, overdrafts (*Ovd*), that is intra-day 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"¹³.

Third, the central bank acts as a residual purchaser of short-term government securities (B_{cb}). Last, the lending facility (R_{cb}^l) is a passive *liquidity-injecting* operation used "at the discretion of individual commercial banks"¹⁴ 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 fulfill 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 market¹⁵.

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 reserves¹⁶ that can be lent out to the interbank market. Second, these holdings are not provided or accommodated by the central bank,

¹⁰Lavoie (2009), page 56.

¹¹Bianchetti and Carlicchi (2013), page 7.

¹²Bindseil (2004), page 49.

¹³Allen (2007), page 36.

¹⁴Bindseil and Würtz (2007), page 58.

¹⁵Instead 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.

¹⁶Free reserves are defined as the amount of reserves not contributing to the fulfillment of reserve requirement.

instead, they "must come at the expense of another commercial bank being unable to meet its reserve requirement"¹⁷.

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 National Central Banks will be left aside¹⁸. Payments in a monetized 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"¹⁹.

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 provides mortgages (M_h) and short-term loans only to households (L_h) for consumption purposes, bank k grants loans only to firms (L_f) to finance production. Households hold deposits at bank j (D_h), and firms hold money balances at bank k (D_f). Both banks hold reserve accounts at the central bank (HPM_j , HPM_k) to fulfill their reserve requirements. In terms of balance sheets, the initial situation is the one described in table (1), leaving aside for the moment mortgages and the central bank's standing facilities.

Table 1: Initial situation

Bank j		Bank k		CB	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
L_h	D_h	L_f	D_f	MRO_j	HPM_j
HPM_j		HPM_k		MRO_k	HPM_k

Now, let us suppose that households buy a product of value C from firms. Since the

¹⁷Rule et al. (2015), page 14.

¹⁸Therefore, 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).

¹⁹Bindseil et al. (2012), page 144.

two agents hold deposits in two different banks, this payment flow implies a transfer of deposits from bank j to bank k . 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"²⁰.

Table (2) summarizes 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).

Table 2: Payment flow²¹

Household		Bank j		Bank k		Firm		CB	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
$D_h[-C]$			$D_h[-C]$		$D_f[+C]$	$D_f[+C]$			$HPM_j[-C]$
		$HPM_j[-C]$		$HPM_k[+C]$					$HPM_k[+C]$

Next, assuming that banks operate "in a system without averaging, thus with a one-day reserve maintenance period"²², 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 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) to the central bank in the form of intra-day credit, which will be provided on demand to guarantee immediate settlement and bear no interest rate²³. This establishes a debt relationship between bank j and the central bank, as described in table (3), and bank j will then need reserves both to repay the credit received from the central bank, and to fulfill 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.

Table 3: Debt *vis-à-vis* the central bank

Bank j		CB	
Assets	Liabilities	Assets	Liabilities
$HPM_j[+]$	$Ovd[+]$	$Ovd[+]$	$HPM_j[+]$

At this point, bank j will need again to acquire reserves in both cases, either only to fulfill its reserve requirement, or also to repay the central bank for the advances

²⁰Graziani (2003), page 62.

²¹Potential changes in households' net worth or firms' inventories are not taken into account to provide a clearer representation of the payment flow.

²²Bindseil (2004), 90.

²³This kind of credit is not remunerated as in the example provided by Whelan (2014), and as specified by Allen (2007) (page 42).

provided. In the context of this paper, since it will be assumed that required reserves are obtained through main refinancing operations provided by the central bank, 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 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 fulfill 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 (4) describes the stocks held by each agent in each sector, providing a static picture of the economic system in question. Inter-sectoral monetary transactions and the flow of funds are captured by the Transaction Matrix in table (5), which depicts the dynamics of the system. Before displaying the two matrices, 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. Two things have to be noticed: i) the only real assets in the model, with no liability counterpart, are houses held by households and physical capital held by firms; ii) housing investments ($\bar{p}_h \Delta H$) are decomposed from business investments (I), which will become clearer from table (5) and once the behavioral equations for households and firms are introduced.

Figure 1: Agents' balance sheet composition

Households		Firms		Government	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
Deposits	Net Worth	Deposits	Net Worth		Bills j
	Loans			Net Worth	Bills k
Houses	Mortgages	Capital	Loans		Bills cb
					Bonds

Bank j		Bank k		Central Bank	
Assets	Liabilities	Assets	Liabilities	Assets	Liabilities
Req. Reserves j	Deposits	Req. Reserves k	Deposits	Bills	Reserves
Bonds			MRO k	MRO j	
	MRO j	Bills		MRO k	
	Overdrafts	O/N IB loans		Overdrafts	
	O/N IB loans	Term IB loans	Net Worth	Lending Facility	Deposit Facility
Loans	Term IB loans	Loans			
	Lending Facility				
Mortgages	Net Worth	Deposit Facility			

Table 4: Balance Sheet Matrix

	Households	Firms	Government	Central Bank	Banks		Σ
					Bank j	Bank k	
Capital stock (K)		+ K					+K
Houses (H)	$+\bar{p}_h H_h$						$+\bar{p}_h H_h$
Deposits (D)	$+D_h$	$+D_f$			$-D_h$	$-D_f$	0
Loans (L)	$-L_h$	$-L_f$			$+L_h$	$+L_f$	0
Mortgages (M)	$-M_h$				$+M_h$		0
Bills (B)			$-B$	$+B_{cb}$	$+B_j$	$+B_k$	0
Bonds (B^{lr})			$-B^{lr}$		$+B^{lr}$		0
Overdrafts (Ovd)				$+Ovd$	$-Ovd$		0
Required Reserves (HPM)				$-HPM$	$+HPM_j$	$+HPM_k$	0
Overnight Interbank Loan (IB_{on})					$-IB_{on}$	$+IB_{on}$	0
Term Interbank Loan (IB_{term})					$-IB_{term}$	$+IB_{term}$	0
Main Refinancing Operations (MRO)				$+MRO$	$-MRO_j$	$-MRO_k$	0
Lending Facility Reserves (R_{cb}^l)				$+R_{cb}^l$	$-R_{cb}^l$		0
Deposit Facility Reserves (R_{cb}^d)				$-R_{cb}^d$		$+R_{cb}^d$	0
Net Wealth: Σ	$+V_h$	$+V_f$	$-(B + B_j^{lr})$	$+V_{cb}$	$+V_{bj}$	$+V_{bk}$	$+\bar{p}_h H_h + K$

Table 5: Transaction Flow Matrix

Operation	Household	Firm		Banks				Central Bank			Σ
		Current	Capital	Bank j		Bank k		Current	Capital	Government	
				Current	Capital	Current	Capital				
Consumption	$-C$	$+C$									0
Government Expenditure		$+G$								$-G$	0
Business Investments		$+I$	$-I$								0
Housing Investments	$-\bar{p}_h \Delta H_h$	$+\bar{p}_h \Delta H_h$									0
Wages	$+W$	$-W$									0
Taxes	$-T$									$+T$	0
Interest on Bills				$+i_b B_{j(-1)}$		$+i_b B_{k(-1)}$		$+i_b B_{cb(-1)}$		$-i_b B_{(-1)}$	0
Interest on Bonds				$+\tilde{i}_b^{lr} B_{(-1)}^{lr}$						$-\tilde{i}_b^{lr} B_{(-1)}^{lr}$	0
Interest on Loans	$-i_{h(-1)}^l L_{h(-1)}$	$-i_{f(-1)}^l L_{f(-1)}$		$+i_{h(-1)}^l L_{h(-1)}$		$+i_{f(-1)}^l L_{f(-1)}$					0
Interest on Deposits	$+i_{h(-1)}^d D_{h(-1)}$	$+i_{f(-1)}^d D_{f(-1)}$		$-i_{h(-1)}^d D_{h(-1)}$		$-i_{f(-1)}^d D_{f(-1)}$					0
Interest on Mortgages	$-\tilde{i}_h^m M_{h(-1)}$			$+i_h^m M_{h(-1)}$							0
Interest on IB_{on}				$-i_{ib(-1)}^{on} IB_{on(-1)}$		$+i_{ib(-1)}^{on} IB_{on(-1)}$					0
Interest on IB_{term}				$-i_{ib(-1)}^{term} IB_{term(-1)}$		$+i_{ib(-1)}^{term} IB_{term(-1)}$					0
Interest on MRO				$-i_{cb}^t MRO_{j(-1)}$		$-i_{cb}^t MRO_{k(-1)}$		$+i_{cb}^t MRO_{(-1)}$			0
Interest on Lending Facility				$-\tilde{i}_{cb}^l R_{cb(-1)}^l$				$+\tilde{i}_{cb}^l R_{cb(-1)}^l$			0
Interest on Deposit Facility						$+\tilde{i}_{cb}^d R_{cb(-1)}^d$		$-\tilde{i}_{cb}^d R_{cb(-1)}^d$			0
Profits of firms	$+Div_f$	$-P_f$	$+P_f^u$								0
Profits of bank j	$+Div_{bj}$			$-P_{bj}$	$+P_{bj}^u$						0
Profits of bank k	$+Div_{bk}$					$-P_{bk}$	$+P_{bk}^u$				0
Profits of CB								$-P_{cb}$		$+P_{cb}$	0
Δ Deposits	$-\Delta D_h$		$-\Delta D_f$		$+\Delta D_h$		$+\Delta D_f$				0
Δ Loans	$+\Delta L_h$		$+\Delta L_f$		$-\Delta L_h$		$-\Delta L_f$				0
Δ Mortgages	$+\Delta M_h$				$-\Delta M_h$						0
Δ Bills					$-\Delta B_j$		$-\Delta B_k$		$-\Delta B_{cb}$	$+\Delta B$	0
Δ Bonds					$-\Delta B^{lr}$					$+\Delta B^{lr}$	0
Δ HPM					$-\Delta HPM_j$		$-\Delta HPM_k$		$+\Delta HPM$		0
Δ MRO					$+\Delta MRO_j$		$+\Delta MRO_k$		$-\Delta MRO$		0
Δ Advances					$+\Delta Ovd$				$-\Delta Ovd$		0
Δ IB_{on}					$+\Delta IB_{on}$		$-\Delta IB_{on}$				0
Δ IB_{term}					$+\Delta IB_{term}$		$-\Delta IB_{term}$				0
Δ Lending Facility					$+\Delta R_{cb}^l$				$-\Delta R_{cb}^l$		0
Δ Deposit Facility							$-\Delta R_{cb}^d$		$+\Delta R_{cb}^d$		0
ΔNet Worth	ΔV_h	0	ΔV_f	0	ΔV_{bj}	0	ΔV_{bk}	0	ΔV_{cb}	0	0
Σ	0	0	0	0	0	0	0	0	0	0	0

3.2 Variables and Accounting Identities

For the sake of consistency of the model, the second step requires to distribute the 50 decisional variables in the Transaction Matrix to each sector, and to extract the identities. All the parameters and exogenous variables both in the matrix and in the whole model are reported with a bar.

- Government: G, T, i_b, B, B^{lr}
- Household: C, D_h, H_h, V_h ;
- Firm: $I, W, P_f, Div_f, P_f^u, D_f$;
- Bank j : $L_h, M_h, i_h^l, i_h^d, i_h^m, P_{bj}, Div_{bj}, P_{bj}^u, B_j, R_{cb}^l, V_{bj}$;
- Bank k : $L_f, i_f^l, i_f^d, P_{bk}, Div_{bk}, P_{bk}^u, R_{cb}^d, IB_{on}, IB_{term}, i_{ib}^{on}, i_{ib}^{term}, B_k, V_{bk}$;
- Central Bank: $HPM, HPM_j, HPM_k, MRO, MRO_j, MRO_k, Ovd, i_{cb}^t, P_{cb}, B_{cb}, V_{cb}$.

From table (5), there are sixteen accounting identities from the ten columns and the six *non-ordinary rows*²⁴ which equalize use of funds (-) to source of funds (+) and sum to zero.

$$C + T + \bar{p}_h \Delta H_h + \bar{i}_h^m M_{(-1)} + \Delta D_h + i_{h(-1)}^l L_{h(-1)} + \Delta V_h \equiv W + Div_f + Div_{bj} + Div_{bk} + \Delta L_h + i_{h(-1)}^d D_{h(-1)} + \Delta M_h \quad (i)$$

$$G + i_b B_{(-1)} + \bar{i}_b^{lr} B_{(-1)}^{lr} \equiv T + P_{cb} + \Delta B + \Delta B^{lr} \quad (ii)$$

$$P_f + W + i_{f(-1)}^l L_{f(-1)} \equiv C + G + I + i_{f(-1)}^d D_{f(-1)} + p_h \Delta H_h \quad (iii)$$

$$I + \Delta D_f \equiv P_f^u + \Delta L_f \quad (iv)$$

$$i_{cb}^t MRO_{j(-1)} + i_{ib(-1)}^{on} IB_{on(-1)} + i_{h(-1)}^d D_{h(-1)} + i_{ib(-1)}^{term} IB_{term(-1)} + P_{bj} + \bar{i}_{cb}^l R_{cb(-1)}^l \equiv i_b B_{j(-1)} + i_{h(-1)}^l L_{h(-1)} + \bar{i}_h^m M_{h(-1)} + \bar{i}_b^{lr} B_{(-1)}^{lr} \quad (v)$$

$$\Delta B_j + \Delta B^{lr} + \Delta HPM_j + \Delta L_h + \Delta M_h \equiv P_{bj}^u + \Delta D_h + \Delta Ovd + \Delta IB_{on} + \Delta IB_{term} + \Delta R_{cb}^l + \Delta MRO_j + \Delta V_{bj} \quad (vi)$$

$$i_{cb}^t MRO_{k(-1)} + P_{bk} + i_{f(-1)}^d D_{f(-1)} \equiv \bar{i}_{cb}^d R_{cb(-1)}^d + i_{f(-1)}^l L_{f(-1)} + i_b B_{k(-1)} + i_{ib(-1)}^{on} IB_{on(-1)} + i_{ib(-1)}^{term} IB_{term(-1)} \quad (vii)$$

$$\Delta HPM_k + \Delta B_k + \Delta L_f + \Delta IB_{on} + \Delta IB_{term} + \Delta R_{cb}^d \equiv P_{bk}^u + \Delta MRO_k + \Delta D_f + \Delta V_{bk} \quad (viii)$$

$$P_{cb} + \bar{i}_{cb}^d R_{cb(-1)}^d \equiv i_{cb}^t (MRO_{j(-1)} + MRO_{k(-1)}) + i_b B_{cb(-1)} + \bar{i}_{cb}^l R_{cb(-1)}^l \quad (ix)$$

²⁴The non-ordinary rows are the ones that contains three entries: agents' profits, government securities, high-powered money and main refinancing operations.

$$\Delta MRO + \Delta Ovd + \Delta R_{cb}^l + \Delta B_{cb} \equiv \Delta HPM + \Delta R_{cb}^d + \Delta V_{cb} \quad (\text{x})$$

$$P_f \equiv P_f^u + Div_f \quad (\text{xi})$$

$$P_{bj} \equiv P_{bj}^u + Div_{bj} \quad (\text{xii})$$

$$P_{bk} \equiv P_{bk}^u + Div_{bk} \quad (\text{xiii})$$

$$\Delta B \equiv \Delta B_j + \Delta B_k + \Delta B_{cb} \quad (\text{xiv})$$

$$\Delta HPM_j + \Delta HPM_k \equiv \Delta HPM \quad (\text{xv})$$

$$\Delta MRO \equiv \Delta MRO_j + \Delta MRO_k \quad (\text{xvi})$$

Among the features of SFC models, if there are M columns and N non-ordinary rows, then there are $(M + N - 1)$ independent accounting identities. As a consequence, one identity must be kept out from the model, the so-called *missing or redundant equation* (Nikiforos and Zezza, 2017), to guarantee the consistency of flows in simulation periods. Since there are 50 endogenous variables and fifteen independent accounting identities, 35 equations should be defined to solve the model.

At this point, it is possible to define each of the unknowns through behavioral equations and/or the identities above²⁵.

Following the institutional context described in the previous section, first the behaviour of the central bank and of the two banks will be described, and then the one of the remaining agents in the model.

3.3 Central Bank

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

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

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

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

Moreover, it is assumed to be accommodating with respect to the advances demanded by bank j , as expressed in equation (4) and explained in the next section.

$$Ovd = D^{Ovd} \quad (4)$$

²⁵The 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, ...). 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, ...).

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 (5). 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”²⁶, 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.

$$i_{cb}^t = \frac{\bar{i}_{cb}^l + \bar{i}_{cb}^d}{2} \quad (5)$$

$$P_{cb} \equiv i_{cb}^t(MRO_{j(-1)} + MRO_{k(-1)}) + i_b B_{cb(-1)} + \bar{i}_{cb}^l R_{cb(-1)}^l - \bar{i}_{cb}^d R_{cb(-1)}^d \quad (6\text{-ix})$$

The monetary authority provides MRO to both banks to replenish their required reserve holdings, as in equations (7) and (8). This specification is in line with Bindseil (2014), since, in absence of autonomous factors, the amount of open market operations under a symmetric corridor approach has to be exactly equal to the reserve requirements. Moreover, the central bank acts as a residual purchaser of government securities to clear the bills market (equation 10-xiv).

$$MRO_j = HPM_j \quad (7)$$

$$MRO_k = HPM_k \quad (8)$$

$$MRO = MRO_j + MRO_k \quad (9\text{-xvi})$$

$$B_{cb} \equiv B - B_j - B_k \quad (10\text{-xiv})$$

3.4 Banks

The goal of the present study is to provide a more complex formalization 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.

²⁶Bindseil (2014), page 56.

The risk of rollover is analyzed 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 frictions²⁷ 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 formalized as follows:

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

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 denominator, TRSF represents the amount of stable funding *required* to be held given liquidity characteristics and residual maturities of

²⁷Financial frictions occur when trade 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).

the assets in banks' balance sheet. Each asset is thus categorized according to its *value of exposure*, which is linked to its degree of liquidity or *power of disposal*²⁸. A *RSF risk factor* equal to zero indicates fully liquid assets; instead, a RSF factor equal to one represents illiquid assets, with maturity greater than one year, that must be entirely refinanced by *stable funding*.

In 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)²⁹. 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 $a_m = \sum a_i L_i / \sum L_i$ and $b_m = \sum b_n A_n / \sum A_n$.

Last, by dividing for a_m , it is possible to derive the minimum stable funding requirement as $L_m = (b_m/a_m) A_m$. At this point, two cases are possible. When $L_m < (b_m/a_m) A_m$, the NSFR is not satisfied and the borrowing bank might prefer to

²⁸In 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.

²⁹In their paper, the authors follow a similar procedure based on the Liquidity Coverage Ratio.

borrow term. On the contrary, when the so-called *desired margin of stable funds*³⁰ is satisfied, in other words when $L_m \geq (b_m/a_m) A_m$, 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 market. This interpretation is embodied in bank j 's decision for overnight interbank loans through equation (11), which defines the bank's degree of stability as an inverse measure for maturity mismatch.

$$DS_m = L_m - \left(\frac{b_m}{a_m} \right) A_m \quad (11)$$

Equations (12)-(15) define the elements composing the minimum stable funding requirement, following the implicit contractual maturities and the respective associated weights of table (6) in the Appendix. More specifically, equations (14) and (15) represent respectively the proportion of available stable funds over total funds, and the fraction of required stable funding over total assets.

$$L_m = D_{h(-1)} + MRO_{j(-1)} + Ovd_{(-1)} + IB_{on(-1)} + IB_{term(-1)} + R_{cb(-1)}^l \quad (12)$$

$$A_m = L_{h(-1)} + HPM_{j(-1)} + B_{j(-1)} + B_{(-1)}^{lr} + M_{h(-1)} \quad (13)$$

$$a_m = \frac{\bar{m}_5 D_{h(-1)} + \bar{m}_6 IB_{term(-1)}}{L_m} \quad (14)$$

$$b_m = \frac{\bar{m}_1 L_{h(-1)} + \bar{m}_2 M_{h(-1)} + \bar{m}_3 B_{j(-1)} + \bar{m}_4 B_{(-1)}^{lr}}{A_m} \quad (15)$$

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

3.4.1 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 payment transfer for households' consumption C , defined in the following section. Its demand for overdrafts (D^{Ovd}) can be summarized by the following piece-wise linear function:

$$D^{Ovd} = \begin{cases} C - HPM_{j(-1)} & \text{if } C \geq HPM_{j(-1)} \\ 0 & \text{otherwise} \end{cases} \quad (16)$$

³⁰This 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 household's or firms' targeted leverage ratio, to be compared to an actual leverage ratio.

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 fulfill its demand on the interbank market in order to repay the central bank for the advances accommodated (IB^D), equations (17)-(19).

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 term demand is residually defined (IB_{term}^D).

$$IB^D = IB_{on}^D + IB_{term}^D = D^{Ovd} \quad (17)$$

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

$$IB_{term}^D = IB^D - IB_{on}^D \quad (19)$$

$$\begin{aligned} \theta = & \bar{\alpha} (\bar{i}_{cb}^l - i_{ib}^{on}) + \bar{\alpha}_1 (i_{ib}^{term} - i_{ib}^{on}) + \bar{\alpha}_2 \frac{DS_m}{|V_{bj(-1)}|} - \bar{\alpha}_3 (\bar{i}_{cb}^l - i_{ib}^{term}) - \\ & - \bar{\alpha}_4 \overline{PDU} \end{aligned} \quad (20)$$

Equation (20) defines θ , which is interpreted as bank j 's *willingness to borrow overnight*, comprised between zero and one. This fraction is dependent on 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 i_{cb}^l , borrowing from another bank is less profitable, hence θ decreases³¹.

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 (12)-(15). 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

³¹Since by construction the overnight interbank interest rate falls within the corridor (equation 32), it can get only closer to the penalty rate, not higher. This reasoning does not apply for the term interbank rate (equation 34), at least not in the baseline scenario.

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 analyzed: 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 light of these factors, bank k 's ability to lend, as expressed in equation (21), is represented by the maximum amount of reserves it can provide to bank j on the interbank market.

$$LF_k = C + R_{cb(-1)}^d \quad (21)$$

In equations (22)-(24), 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_bW), similar to Le Heron (2007), Le Heron and Mouakil (2008) and Le Heron (2011).

$$IB^S = IB_{on}^S + IB_{term}^S = LF_k \quad (22)$$

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

$$IB_{term}^S = IB^S - IB_{on}^S \quad (24)$$

$$\begin{aligned} L_bW = & \bar{\sigma} + \bar{\sigma}_1 \overline{PDU} + \bar{\sigma}_2(i_{ib}^{on} - \bar{i}_{cb}^d) + \bar{\sigma}_3(|DER_j| - \bar{\gamma}) - \bar{\sigma}_4(i_{ib}^{term} - i_{ib}^{on}) - \\ & - \bar{\sigma}_5(i_{ib}^{term} - \bar{i}_{cb}^d) - \bar{\sigma}_6 QR \end{aligned} \quad (25)$$

The L_bW 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 round³². The lending bank's audit practises 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"³³.

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 (i_{cb}^d). If the difference between the two rates increases, that is to say that given i_{cb}^d , the overnight rate increases, the profitability to lend overnight is higher, thus leading to a rise of L_bW . Fourth, the difference between the borrowing bank's *debt-to-equity ratio* (DER_j), defined in equation (26) 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"³⁴. 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 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.

$$DER_j = \frac{Ovd_{(-1)} + IB_{on(-1)} + IB_{term(-1)} + MRO_{j(-1)}}{V_{bj(-1)}} \quad (26)$$

The fifth element refers to the the interbank market spread. When i_{ib}^{term} increases or i_{ib}^{on} decreases, widening their difference, L_bW 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

³²In 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.

³³Murinde et al. (2016), page 3.

³⁴Popoyan et al. (2017), page 13.

term rather than overnight, hence L_bW 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 (27). 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"³⁵, 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 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_bW 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.

$$QR = \frac{L_{h(-1)} + B_{j(-1)} + HPM_{j(-1)}}{Ovd_{(-1)} + MRO_{j(-1)} + IB_{on(-1)} + R_{cb(-1)}^l} \quad (27)$$

At this point, table (7) in the Appendix depicts what happens on the interbank market for every possible value of θ and L_bW .

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 (28) and (29), 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

³⁵Popoyan et al. (2017), page 7.

bank by accessing the deposit facility (R_{cb}^d). Since this “two-sided”³⁶ 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.

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

$$R_{cb}^d = \begin{cases} IB^S & \text{if } \theta = 0 \text{ and } L_b W = 1 \quad \text{or } \theta = 1 \text{ and } L_b W = 0 \\ IB_{on}^S & \text{if } \theta = 0 \quad \text{and } 0 < L_b W < 1 \\ IB_{term}^S & \text{if } \theta = 1 \quad \text{and } 0 < L_b W < 1 \\ 0 & \text{otherwise} \end{cases} \quad (29)$$

The stocks of interbank loans can be defined in 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 (38) and (40)). 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 (30) and (31) define respectively the stock of overnight interbank loans and the stock of term interbank loans.

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

$$IB_{term} = \begin{cases} IB_{term}^S & \text{if } IB_{term}^D > IB_{term}^S \\ IB_{term}^D & \text{if } IB_{term}^D < IB_{term}^S \end{cases} \quad (31)$$

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.

³⁶Bindseil and Jablecki (2011), page 14.

3.4.2 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 respectively clear the overnight segment and the term one can be defined according to equations (32) and (34), with $\bar{\sigma}_{ib}$ exogenous parameter representing banks' sensitivity to excess demand or excess supply captured by equations (33) and (35).

$$i_{ib}^{on} = \bar{i}_{cb}^d + \frac{\bar{i}_{cb}^l - \bar{i}_{cb}^d}{1 + e^{-(\bar{\sigma}_{ib}\epsilon_{on})}} \quad (32)$$

$$\epsilon_{on} = IB_{on}^D - IB_{on}^S \quad (33)$$

$$i_{ib}^{term} = \bar{\eta}_1 + \frac{\bar{\eta}_2}{1 + e^{-(\bar{\sigma}_{ib}\epsilon_{term})}} \quad (34)$$

$$\epsilon_{term} = IB_{term}^D - IB_{term}^S \quad (35)$$

Among the advantages of this formalization of interest rates, first, it ensures that the overnight interbank rate falls within the central bank's corridor $(\bar{i}_{cb}^d, \bar{i}_{cb}^l)$ 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 (5), as it is expected when a symmetric corridor approach is put into place. Indeed, under this formalization, 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"³⁷ 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, in the baseline scenario it will be analyzed 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 practises.

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

³⁷Bindseil (2004), page 86.

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 the Appendix.

3.4.3 Credit Market

The setting of the credit market and of banks' liquidity preferences will be treated in a very simple fashion. On the one hand, bank j can choose between four assets: short-term loans, bonds, mortgages and bills. On the other, bank k can choose between short-term loans and bills only.

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

$$\begin{bmatrix} L_h \\ B^{lr} \\ M_h \\ B_j \end{bmatrix} = \begin{bmatrix} \bar{\lambda}_{10} \\ \bar{\lambda}_{20} \\ \bar{\lambda}_{30} \\ \bar{\lambda}_{40} \end{bmatrix} F_j + \begin{bmatrix} \bar{\lambda}_{11} & -\bar{\lambda}_{12} & -\bar{\lambda}_{13} & -\bar{\lambda}_{14} \\ -\bar{\lambda}_{21} & \bar{\lambda}_{22} & -\bar{\lambda}_{23} & -\bar{\lambda}_{24} \\ -\bar{\lambda}_{31} & -\bar{\lambda}_{32} & \bar{\lambda}_{33} & -\bar{\lambda}_{34} \\ -\bar{\lambda}_{41} & -\bar{\lambda}_{42} & -\bar{\lambda}_{43} & \bar{\lambda}_{44} \end{bmatrix} \begin{bmatrix} i_h^l \\ i_b^{lr} \\ i_h^m \\ i_b \end{bmatrix} F_j \quad (d)$$

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

Bank j 's loans to households and bank k 's loans to firms can be expressed as in equations (36) and (37), 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 households and firms.

$$L_h = [\bar{\lambda}_{10} + \bar{\lambda}_{11}i_h^l - \bar{\lambda}_{12}i_b^{lr} - \bar{\lambda}_{13}i_h^m - \bar{\lambda}_{14}i_b]F_j \quad (36)$$

$$L_f = [\bar{\beta}_{10} + \bar{\beta}_{11}i_f^l - \bar{\beta}_{12}i_b]F_k \quad (37)$$

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

$$F_j = F_{j(-1)} + (L_h^D + M_h^D - F_{j(-1)})(1 - CR_h) \quad (38)$$

$$CR_h = \bar{\omega}_1 \overline{PDU} + \bar{\omega}_2 \frac{(L_{h(-1)} + M_{h(-1)})}{V_{h(-1)}} \quad (39)$$

$$F_k = F_{k(-1)} + (L_f^D - F_{k(-1)})(1 - CR_f) \quad (40)$$

$$CR_f = \bar{\omega}_1 \overline{PD\bar{U}} + \bar{\omega}_2 \frac{L_{f(-1)}}{K_{(-1)}} \quad (41)$$

In light of bank j 's liquidity preferences, equations (42)-(43) define respectively the amount of long-term government securities demanded and the amount of mortgages supplied to households.

$$B_j^{lr} = [\bar{\lambda}_{20} - \bar{\lambda}_{21}i_h^l + \bar{\lambda}_{22}i_b^{lr} - \bar{\lambda}_{23}i_h^m - \bar{\lambda}_{24}i_b]F_j \quad (42)$$

$$M_h = [\bar{\lambda}_{30} - \bar{\lambda}_{31}i_h^l - \bar{\lambda}_{32}i_b^{lr} + \bar{\lambda}_{33}i_h^m - \bar{\lambda}_{34}i_b]F_j \quad (43)$$

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

$$B_j = F_j - L_h - B_j^{lr} - M_h \quad (44)$$

$$B_k = F_k - L_f \quad (45)$$

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 and the one on mortgages. 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 interest rate it pays to replenish its reserve requirement via MRO. For bank j , instead, funding costs (f_{c_j}) are defined in equation (46), and are expressed as the average between the cost of acquiring reserves through main refinancing operations, i_{cb}^t , the costs faced on the interbank market i_{ib}^* , whose value depends on θ and L_bW , and the cost of accessing the central bank's lending facility when needed, i_{cb}^{l*} .

$$f_{c_j} = \frac{i_{cb}^t + i_{ib}^* + i_{cb}^{l*}}{\zeta} \quad (46)$$

$$i_{ib}^* = \begin{cases} i_{ib}^{on} & \text{if } \theta = L_bW = 1 \text{ or } 0 < \theta < 1 \text{ and } L_bW = 1 \\ & \text{or } \theta = 1 \text{ and } 0 < L_bW < 1 \\ i_{ib}^{term} & \text{if } \theta = L_bW = 0 \text{ or } 0 < \theta < 1 \text{ and } L_bW = 0 \\ & \text{or } \theta = 0 \text{ and } 0 < L_bW < 1 \\ \frac{(i_{ib}^{on} + i_{ib}^{term})}{2} & \text{if } 0 < \theta < 1 \text{ and } 0 < L_bW < 1 \\ 0 & \text{otherwise} \end{cases} \quad (47)$$

$$i_{cb}^{l*} = \begin{cases} \bar{i}_{cb}^l & \text{if } R_{cb}^l \neq 0 \\ 0 & \text{otherwise} \end{cases} \quad (48)$$

$$\zeta = \begin{cases} 2 & \text{if } i_{ib}^* = 0 \text{ and } i_{cb}^{l*} \neq 0 \text{ or } i_{ib}^* \neq 0 \text{ and } i_{cb}^{l*} = 0 \\ 3 & \text{if } i_{ib}^* = i_{cb}^{l*} \neq 0 \end{cases} \quad (49)$$

On these premises, the interest rates determination is simply based on constant *mark-up* and *mark-down* rules as in Le Heron and Mouakil (2008), equations (50)-(54), and assumed to be of same value for bank k .

$$i_h^l = f_{c_j} + \bar{\chi}_1 \quad (50)$$

$$i_h^d = f_{c_j} - \bar{\chi}_2 \quad (51)$$

$$i_h^m = i_{ib}^{term} + \bar{\chi}_3 \quad (52)$$

$$i_f^l = i_{cb}^t + \bar{\chi}_1 \quad (53)$$

$$i_f^d = i_{cb}^t - \bar{\chi}_2 \quad (54)$$

$$P_{bj} \equiv i_b B_{j(-1)} + i_{h(-1)}^l L_{h(-1)} + i_b^{lr} B_{(-1)}^{lr} + i_{h(-1)}^m M_{h(-1)} - i_{cb}^t MRO_{j(-1)} - \quad (55-v) \\ - i_{h(-1)}^d D_{h(-1)} - \bar{i}_{cb}^l R_{cb(-1)}^l - i_{ib(-1)}^{on} IB_{on(-1)} - i_{ib(-1)}^{term} IB_{term(-1)}$$

$$P_{bk} \equiv \bar{i}_{cb}^d R_{cb(-1)}^d + i_{f(-1)}^l L_{f(-1)} + i_b B_{k(-1)} + i_{ib(-1)}^{on} IB_{on(-1)} + \quad (56-vii) \\ + i_{ib(-1)}^{term} IB_{term(-1)} - i_{f(-1)}^d D_{f(-1)} - i_{cb}^t MRO_{k(-1)}$$

$$Div_{bj} = \bar{s}_j P_{bj} \quad (57)$$

$$Div_{bk} = \bar{s}_k P_{bk} \quad (58)$$

$$P_{bj}^u \equiv P_{bj} - Div_{bj} \quad (59-xii)$$

$$P_{bk}^u \equiv P_{bk} - Div_{bk} \quad (60-xiii)$$

The last six equations define respectively total banks' profits (equations 55-v and 56-vii), dividends distributed to the household sector (equations 57 and 58), and retained earnings of the banking sector (equations 59-xii and 60-xiii).

$$V_{bj} \equiv V_{bj(-1)} + \Delta HPM_j + \Delta B_j + \Delta B^{lr} + \Delta L_h + \Delta M_h - P_{bj}^u - \quad (61-vi) \\ - \Delta D_h - \Delta Ovd - \Delta IB_{on} - \Delta IB_{term} - \Delta MRO_j - \Delta R_{cb}^l$$

$$V_{bk} \equiv V_{bk(-1)} + \Delta B_k + \Delta HPM_k + \Delta L_f + \Delta IB_{on} + \Delta IB_{term} + \quad (62-viii) \\ + \Delta R_{cb}^d - P_{bk}^u - \Delta MRO_k - \Delta D_f$$

In conclusion, equations (61-vi) and (62-viii) characterize banks' net worth via two of the identities from the transaction flow matrix.

3.5 Government, Households and Firms

Government's behaviour, together with that of households and firms, is built following Le Heron and Mouakil (2008) and Dafermos (2012).

About the government sector, government expenditure (G) is assumed to be growing at the same rate (g_y) of national income (Y).

$$G = G_{(-1)}(1 + g_{y(-1)}) \quad (63)$$

$$g_y = \frac{\Delta Y}{Y_{(-1)}} \quad (64)$$

$$Y = C + I + G + \bar{p}_h \Delta H_h \quad (65)$$

Investments are decomposed in two parts: i) business investments (I), and ii) housing investments ($p_h \Delta H_h$), both defined in the following paragraphs.

Taxes (T) are collected only from households, as a share of their wages (W), and government debt is financed by the issuance of both short-term securities (equation 67-i) and long-term ones (equation 68). While short-term bills are demanded by both banks, long-term bonds are demanded by bank j only, whose variables have been in the previous section. The government is assumed to issue bills according to identity (ii) and to accommodate any quantity of bonds demanded by bank j to guarantee market clearing.

$$T = \bar{\tau} W_{(-1)} \quad (66)$$

$$B \equiv B_{(-1)} + i_b B_{(-1)} + G + i_b^{lr} B_{(-1)}^{lr} - T - P_{cb} - \Delta B^{lr} \quad (67\text{-ii})$$

$$B^{lr} = B_j^{lr} \quad (68)$$

Moreover, the interest rate on bills (i_b) is assumed to be identical to the targeted interest rate of the central bank (i_{cb}^t), and the interest rate on bonds (i_b^{lr}) is set exogenously.

$$i_b = i_{cb}^t \quad (69)$$

Households decide how much to consume on the basis of their expected total disposable income (Y_d^a), composed of both labour and financial income as in Zezza and Dos Santos (2004), and their net worth from the earlier period (V_h), defined as a residual variable via the accounting identity (i) issued by the transaction flow matrix, similarly to Dafermos (2012).

$$C = \bar{a}_1 Y_d^a + \bar{a}_2 V_{h(-1)} \quad (70)$$

$$V_h \equiv V_{h(-1)} + Y_d + \Delta L_h + \Delta M_h - C - \bar{p}_h \Delta H_h - \Delta D_h \quad (71\text{-i})$$

Their financial income is considered to be the result of interest payments on deposits held at bank j , net of the outflow of interest payments on the loans and mortgages received, and the dividends distributed by firms and banks. Expectations are assumed to be adaptive as in equation (72).

$$Y_d^a = Y_{d(-1)} + \bar{\phi} (Y_{d(-1)} - Y_{d(-1)}^a) \quad (72)$$

$$Y_d = W + i_{h(-1)}^d D_{h(-1)} + Div_f + Div_{bj} + Div_{bk} - T - i_{h(-1)}^l L_{h(-1)} - i_{h(-1)}^m M_{h(-1)} \quad (73)$$

The amount of deposits held at bank j determines how much households will save out of their disposable income. This is assumed to be a proportion \bar{s}_w of their income netted of any change in consumption.

$$D_h = \bar{s}_w Y_d - \Delta C \quad (74)$$

As in Dafermos (2012), and to keep things simple, households' demand for loans for consumption purposes is a constant and exogenous fraction \bar{b} of their total disposable income (Y_d).

$$L_h^D = \bar{b} Y_d \quad (75)$$

Following Cao (2015), a simple housing market is included in the present model. Households engage in housing investments (H_h) whose demand is defined in equation (76) and depends negatively on house prices (\bar{p}_h), exogenous in the context of this analysis, and past interest rates on mortgages ($i_{h(-1)}^m$). For simplicity, their demand for mortgages to bank j is defined via equation (77), dependent only on an autonomous component $\bar{\delta}_3$ and on the mortgage rate charged in the previous period.

$$H_h = \bar{\delta}_0 - \bar{\delta}_1 \bar{p}_h - \bar{\delta}_2 i_{h(-1)}^m \quad (76)$$

$$M_h^D = \bar{\delta}_3 - \bar{\delta}_4 i_{h(-1)}^m \quad (77)$$

The firms' sector is characterized by the following specification. The stock of capital (K) is supposed to be dependent on the level of net investments (I) and to depreciate at a constant rate $\bar{\delta}$. Moreover, equation (79) defines desired investments as a proportion (\bar{g}_k) of the past stock of capital. Net investments are dependent both on unretained earnings (P_f^u) and on their reliance on external finance.

$$K = K_{(-1)} - \bar{\delta} K_{(-1)} + I \quad (78)$$

$$I_d = \bar{g}_k K_{(-1)} \quad (79)$$

$$I \equiv P_f^u + \Delta L_f - \Delta D_f \quad (80\text{-iv})$$

As in Godley and Lavoie (2006), prices are determined as a constant *mark-up* (ρ) on unit direct costs (UDC). These two equations, (f) and (g), are used in order to determine wages paid to households (equation 81). Indeed, this model has no inflation and prices are set exogenously equal to one, following Le Heron and Mouakil (2008). Firms' total profits are derived from identity (iii).

$$p = (1 + \bar{\rho}) UDC \quad (f)$$

$$UDC = \frac{W}{Y} \quad (g)$$

$$W = \frac{Y}{1 + \bar{\rho}} \quad (81)$$

$$P_f \equiv Y + \bar{p}_h \Delta H_h + i_{f(-1)}^d D_{f(-1)} - W - i_{f(-1)}^l L_{f(-1)} \quad (82\text{-}iii)$$

Following Caiani et al. (2016), a fraction \bar{s} of total firms' profits, as well as the profits of banks, is assumed to be distributed to households in the form of dividends, equation (83). The undistributed portion of profits is defined through a re-formulation of identity (xi).

$$Div_f = \bar{s} P_f \quad (83)$$

$$P_f^u = P_f - Div_f \quad (84\text{-}xi)$$

Firms' demand for external finance (L_f^D) depends on the proportion of loans rationed in the previous period, expressed by the difference between the demand for loans and the stock of loans actually received, and desired investments.

$$L_f^D = L_{f(-1)}^D - L_{f(-1)} + I_d \quad (85)$$

Similarly to the household sector, equation (86) defines firms' holding of money balances at bank k as a proportion \bar{s}_w of wages paid to households, as in Caiani et al. (2016), plus any change in consumption.

$$D_f = \bar{s}_w W + \Delta C \quad (86)$$

Last, the redundant equation, re-formalized as in equation (87-x), refers to the central bank's capital account and is used to test whether any accounting error has been committed (Lavoie and Godley, 2001). Also, it logically implies two consequences: i) the central bank's money is supplied to the system via main refinancing operations, overdrafts, bills residually purchased and net use of standing facilities; ii) the amount of legal reserves the private sector holds equals the amount of the monetary policy operations the central bank conducted.

$$V_{cb} \equiv MRO + Ovd + B_{cb} + R_{cb}^l - R_{cb}^d - HPM \quad (87\text{-}x)$$

The 50 variables of the transaction flow matrix have been defined by the introduction of 37 more variables³⁸. Since the number of unknowns and the number of equations coincides (87) and all the independent identities have been used, the model is now closed.

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, 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 87 unknowns in 87 equations into 47 unknowns in 47 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 non-linearity 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_bW); 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) and the variables defining credit rationing in the credit market (CR_h and CR_f); vi) the equation defining

³⁸The 37 new variables divided per sector are the following:

Government: Y, g_y ;

Household: Y_d, Y_d^a, L_h^D, M_h^D ;

Firm: K, I_d, L_f^D ;

Bank j : $L_m, A_m, a_m, b_m, DS_m, D^{ovd}, IB^D, IB_{on}^D, IB_{term}^D, \theta, F_j, B_j^{lr}, CR_h, f_{c_j}, i_{ib}^*, i_{cb}^{l*}, \zeta$;

Bank k : $LF_k, IB^S, IB_{on}^S, IB_{term}^S, L_bW, QR, \epsilon_{on}, \epsilon_{term}, F_k, CR_f, DER_j$.

government expenditure (G) has been changed with the one deriving from the SS condition of balanced government budget³⁹; 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 (8) in the Appendix, 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”⁴⁰, by imposing two transformations to flows and lagged endogenous variables: for any generic endogenous variable X , it must hold that $X_{(-1)} = X / (1 + g_{ss})$, and that $\Delta X = X (g_{ss} / (1 + g_{ss}))$.

The adoption of this approach has allowed the computation of the initial values of stocks and flows, summarized in tables (10) and (11) in the Appendix, 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 2(2a), is strongly related to the dynamics of banks' willingness to borrow (θ) and lend overnight ($L_b W$), figure 2(2e). Indeed, the lower amount of overnight interbank loans exchanged in the interbank market relative to the term ones results from the low values of θ and $L_b W$, which are close and stable at a level slightly higher than 0.2. A closer look at the elements influencing these two measures suggests that the components of bank j 's balance sheet seem to have a higher impact than interbank market interest rates. Indeed, the shape of the curves of interbank loans mainly follow the borrowing bank's degree of stability⁴¹, affecting θ , and its debt-to-equity and quick ratios (figure 2(2j)), impacting $L_b W$, and do not seem very much influenced by the high volatility of the outside spreads $[(\bar{i}_{cb}^l - i_{ib}^{on})$ and $(\bar{i}_{cb}^l - i_{ib}^{term})$; $(i_{ib}^{on} - \bar{i}_{cb}^d)$ and $(i_{ib}^{term} - \bar{i}_{cb}^d)]$ depicted in figures 2(2h) and 2(2g), on the one hand, and of the inside spread $[(i_{ib}^{term} - i_{ib}^{on})]$ in figure 2(2i), on the other.

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

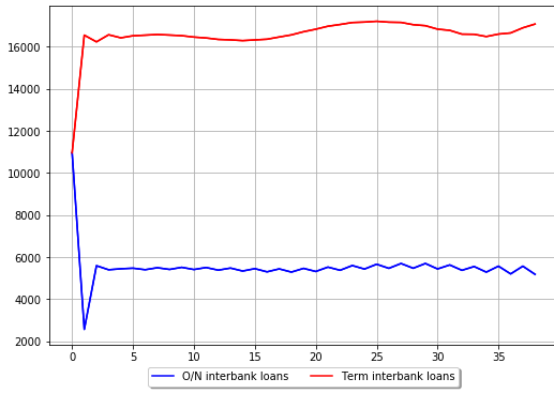
³⁹By imposing the equality between G and T , expressed via equation (66), and substituting for W , equation (81), the resulting SS expression for government expenditure is $G = (\bar{\tau}Y)/(1 + \bar{\rho})$.

⁴⁰Veneziani and Zamparelli (2018), page 56.

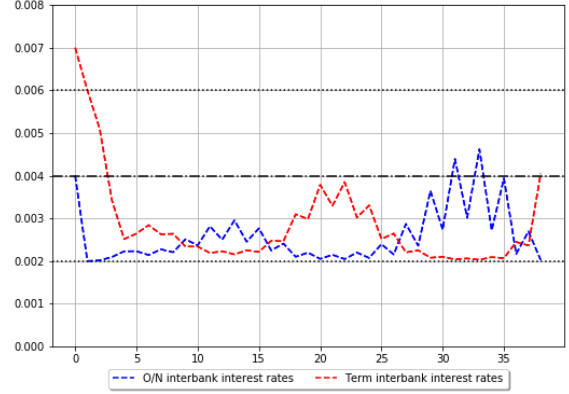
⁴¹The degree of stability is depicted in thousands by figure 2(2c) and in a range between zero and one by figure 2(2d), as also in the following figures.

total liabilities, show the presence of a constant maturity mismatch in bank j 's balance sheet, captured by the yellow line in figure 2(2d). Moreover, the level in thousands of bank j 's degree of stability, figure 2(2c), definitely results from the higher amounts of term contracts the interbank actors have exchanged over time. About the interest rates, figure 2(2b) captures the dynamics of the interbank interest rates, and figure 2(2i) 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 2(2f)). Indeed, over the interval 17-25, the term rate is higher than the overnight one, as a result of excess demand in the term segment, which is supposed to have triggered a slight increase in term interbank loans.

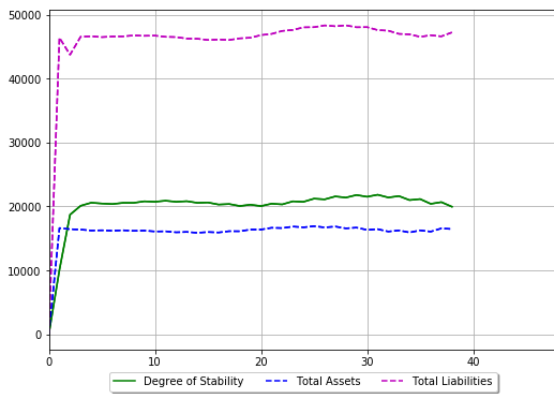
Figure 2: Dynamics of the Baseline Scenario



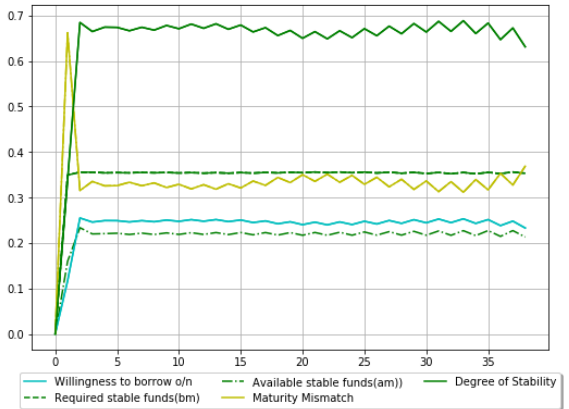
(2a) Interbank loans



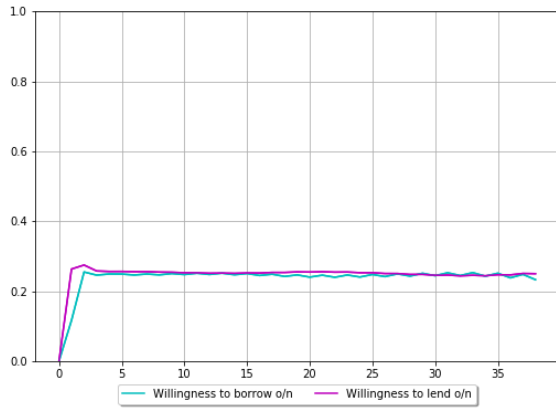
(2b) Interbank interest rates



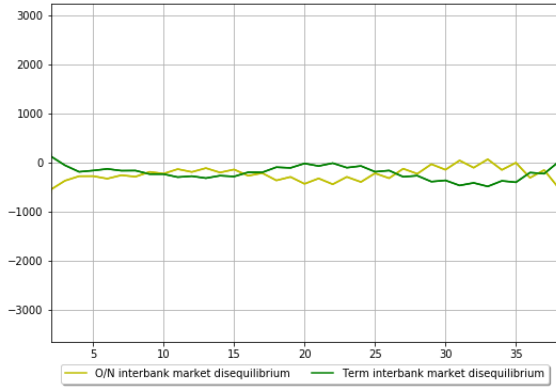
(2c) Degree of Stability



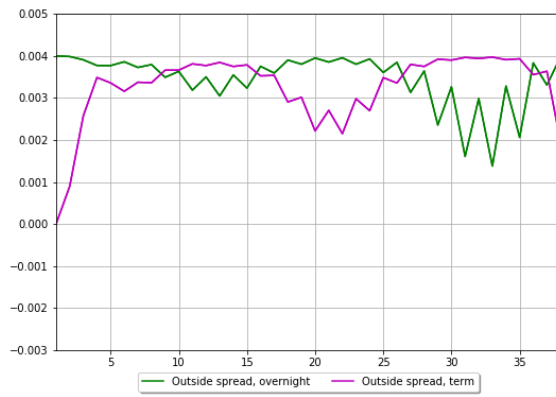
(2d) Maturity Mismatch



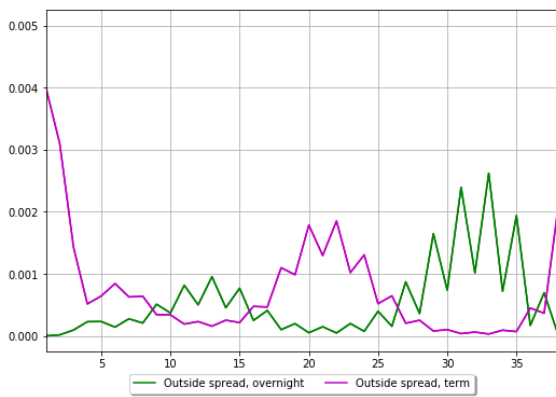
(2e) θ and $L_b W$



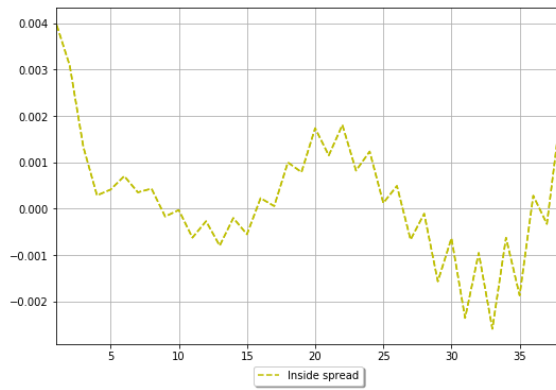
(2f) Interbank market disequilibrium



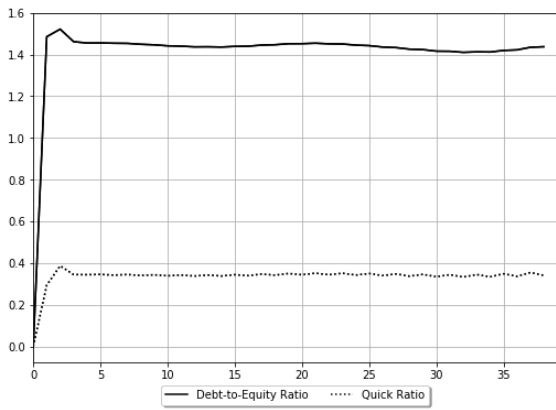
(2g) Borrowing bank outside spreads



(2h) Lending bank outside spreads



(2i) Interbank interest rates spread



(2j) Debt-to Equity Ratio and Quick Ratio

4.2 Perceived Uncertainty Shock

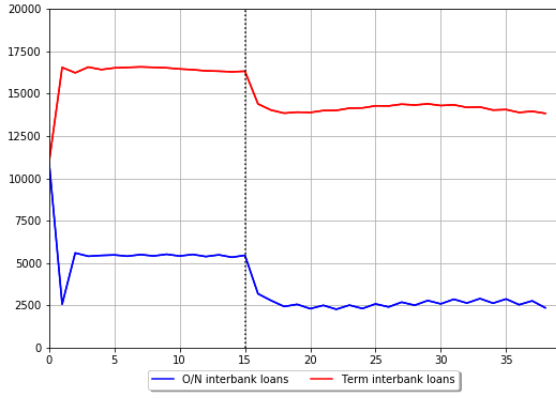
As a first experiment, the simulated economy has been hit by an uncertainty shock. In period 15, the level of the exogenous variable PDU has been drastically increased from 0.1 to 0.6, whose effects to the dynamics of interbank interactions are captured in figure 3. After the shock, represented by a dotted black line, the volumes exchanged in the interbank market (figure 3(3a)) decrease relative to the baseline scenario, both in the overnight and in the term segment, and stabilize at a lower level over the time interval. As a result of the opposite influence of PDU to θ and $L_b W$, interbank demand and supply take divergent paths, figures 3(3e) and 3(3f). An increase in the perceived degree of uncertainty from the borrowing bank's perspective leads to a decline in bank j 's degree of stability inducing bank j to prefer term interbank loans. This happened because of a sharp decrease in total liabilities (equation 11), mainly driven by interbank funds, as it can be noticed from figures 3(3m) and 3(3n). From the lending bank's point of view, the increasing debt-to-equity ratio (figure 3(3l)) suggests that bank j 's ability to repay its obligations has deteriorated following the shock due to a decrease in its net worth. This event leads bank k to be more willing to engage in overnight interbank contracts, as also depicted from figure 3(3g). 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 (figure 3(3h)), which cause interbank exchanges to follow the term supply, on the one hand, and the overnight demand, on the other.

As a consequence of the price clearing mechanism in the interbank market, figure 3(3b), the interest rates spread gets exacerbated, with the term interbank rate becoming equal to the ceiling, and the overnight one equal to the floor. Therefore, the outside spread between the ceiling and the term interbank rate, figure 3(3i), becomes null, and the one between the ceiling and the overnight rate becomes equal to the width of the corridor. The opposite situation is reproduced for the lending bank with respect to the deposit rate of the central bank, figure 3(3j).

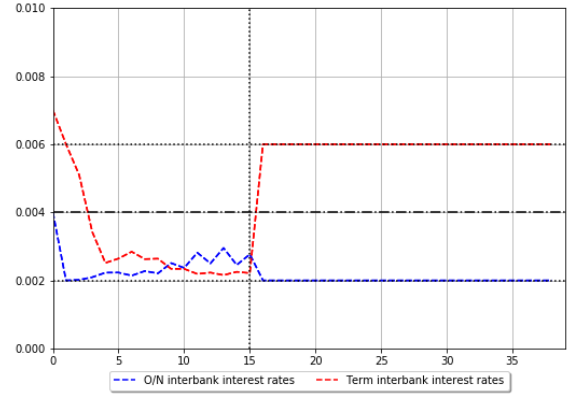
Bank j 's maturity mismatch can be captured in figure 3(3d). Immediately after the shock, the level of maturity mismatch increases, leading θ to decrease by the same amount. Overall, in a situation of higher perceived uncertainty in the interbank market, both the downward trend of the borrowing bank's degree of stability and the increasing reluctance of the lending bank to provide term funds, captured by the rise in bank k 's willingness to lend overnight, have led to a stronger dynamic of the spread.

However, the very high term interest rate seems not to discourage bank j 's preference for term interbank contracts. This aspect is probably linked to the increasing maturity mismatch emerging by the drop in the degree of stability, whose effects are again predominant in determining the final volumes exchanged in the postulated segments of the interbank market.

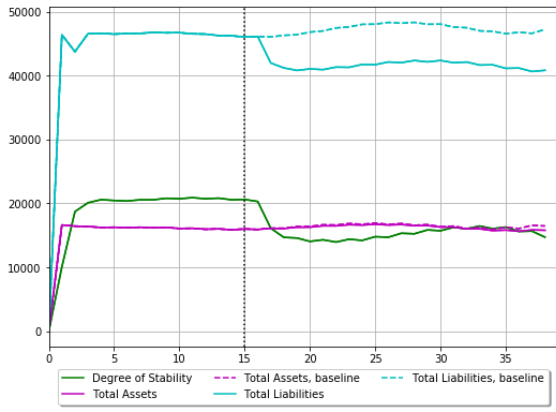
Figure 3: Dynamics after a shock to Perceived Degree of Uncertainty (PDU)



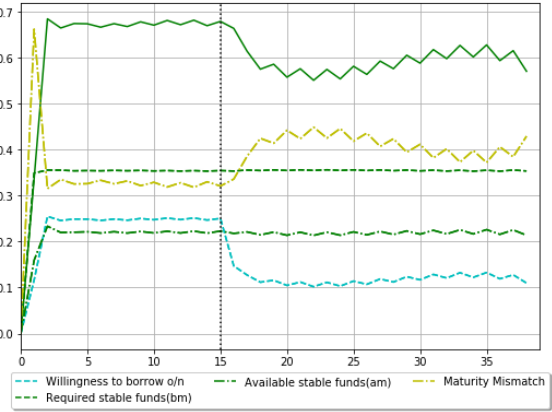
(3a) Interbank loans



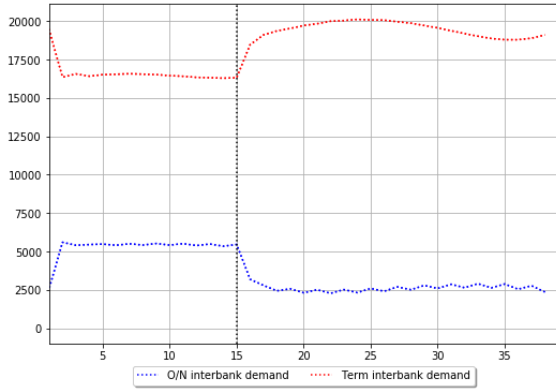
(3b) Interbank interest rates



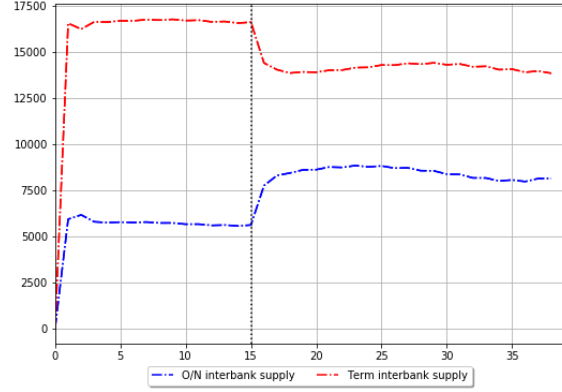
(3c) Degree of Stability



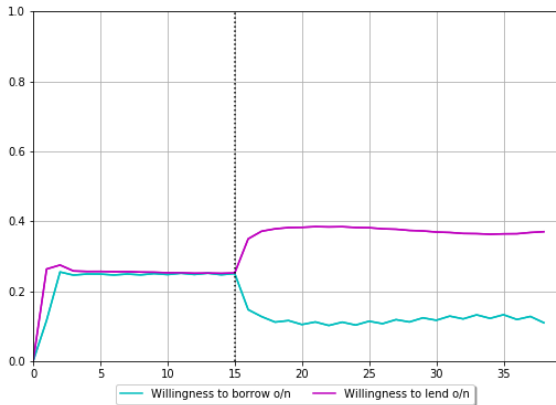
(3d) Maturity Mismatch



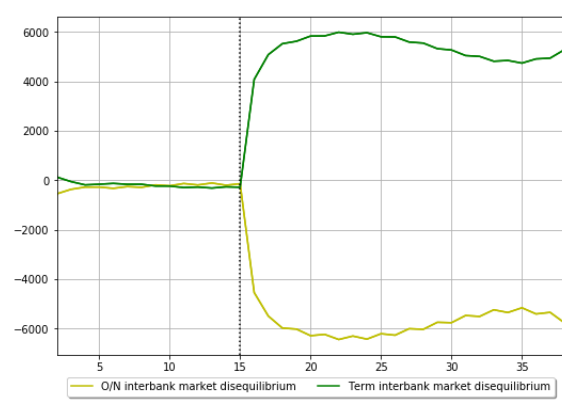
(3e) Interbank demand



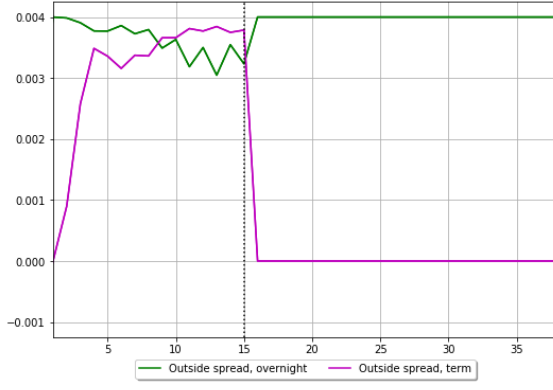
(3f) Interbank supply



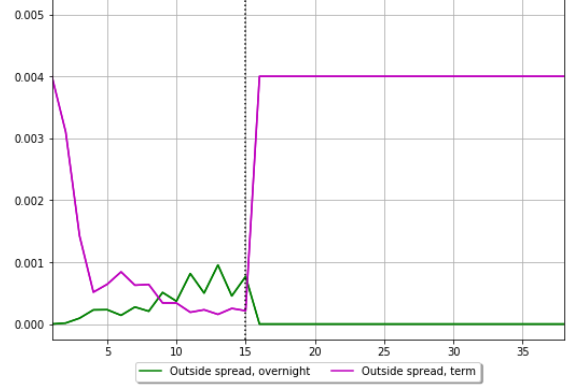
(3g) θ and $L_b W$



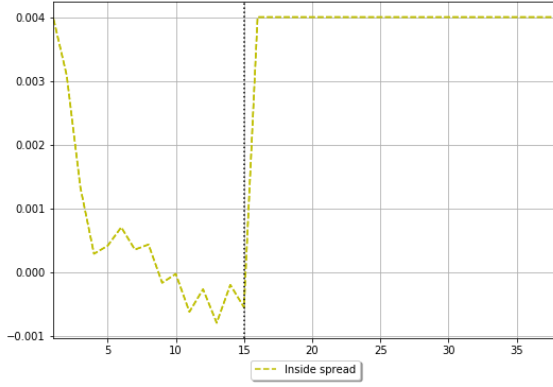
(3h) Interbank disequilibrium



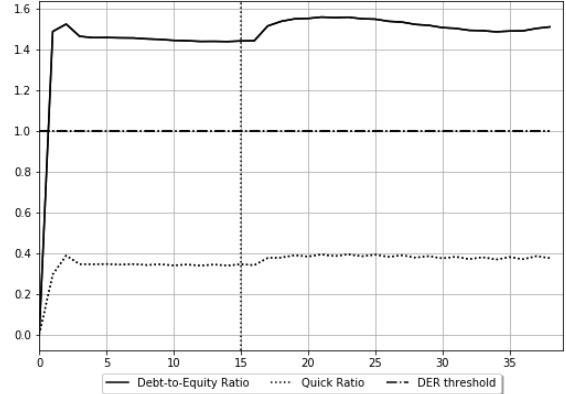
(3i) Borrowing bank outside spreads



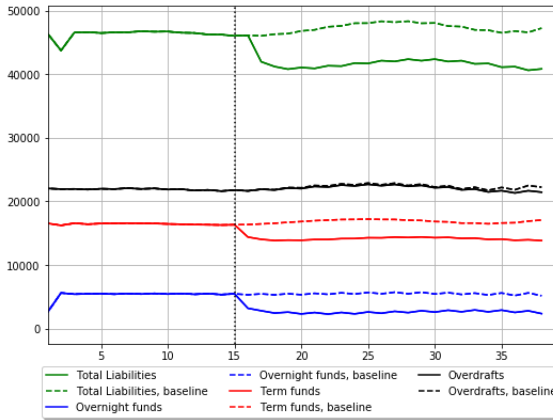
(3j) Lending bank outside spreads



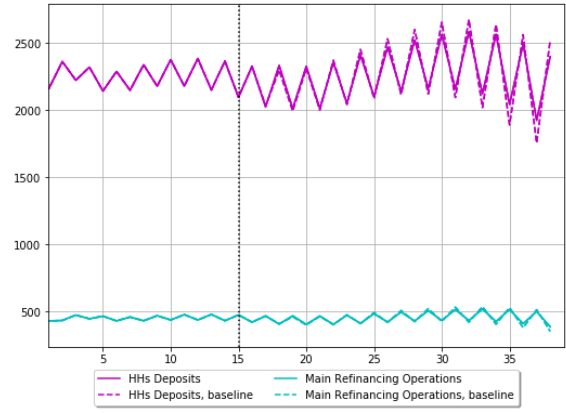
(3k) Interbank interest rates spread



(3l) Debt-to-Equity Ratio and Quick Ratio



(3m) Bank j 's liabilities



(3n) Deposits and MRO

About the credit market, the rise in uncertainty had a small impact on the interest rates charged to households and firms (figure 4(4a)). Indeed, with respect to households, the interest rates on loans and mortgages slightly increase compared to the baseline scenario (dotted lines). As regards the firms sector, increased uncertainty seems to have no effect on the interest rate on loans. This might be 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. Both credit rationing measures increase by 11 basis points relative to the baseline scenario. From figure 4(4c) it seems that the shock barely affects the volume of funds effectively lent in the credit market. To better capture the effect of an increase in uncertainty on

credit rationing, figure 4(4d) shows the ratios of loans to the demanded quantities of both households and firms, similarly to Le Heron and Mouakil (2008). Households' effective credit rationing is not affected by the shock, being constant with respect to the baseline scenario, while firms seem to suffer slightly more over the period 27-34, yet without any considerable deviation from the baseline scenario. As a result, the influence of uncertainty on the credit market appears to be very low probably because the rise in credit rationing has not been strong enough for the transmission of the shock.

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 5 that only at this highest level of uncertainty interbank frictions in the market, triggered by banks' maturity preferences, lead to the recourse by the lending bank to the central bank's deposit facility.

Figure 4: Credit market under increased Perceived Degree of Uncertainty

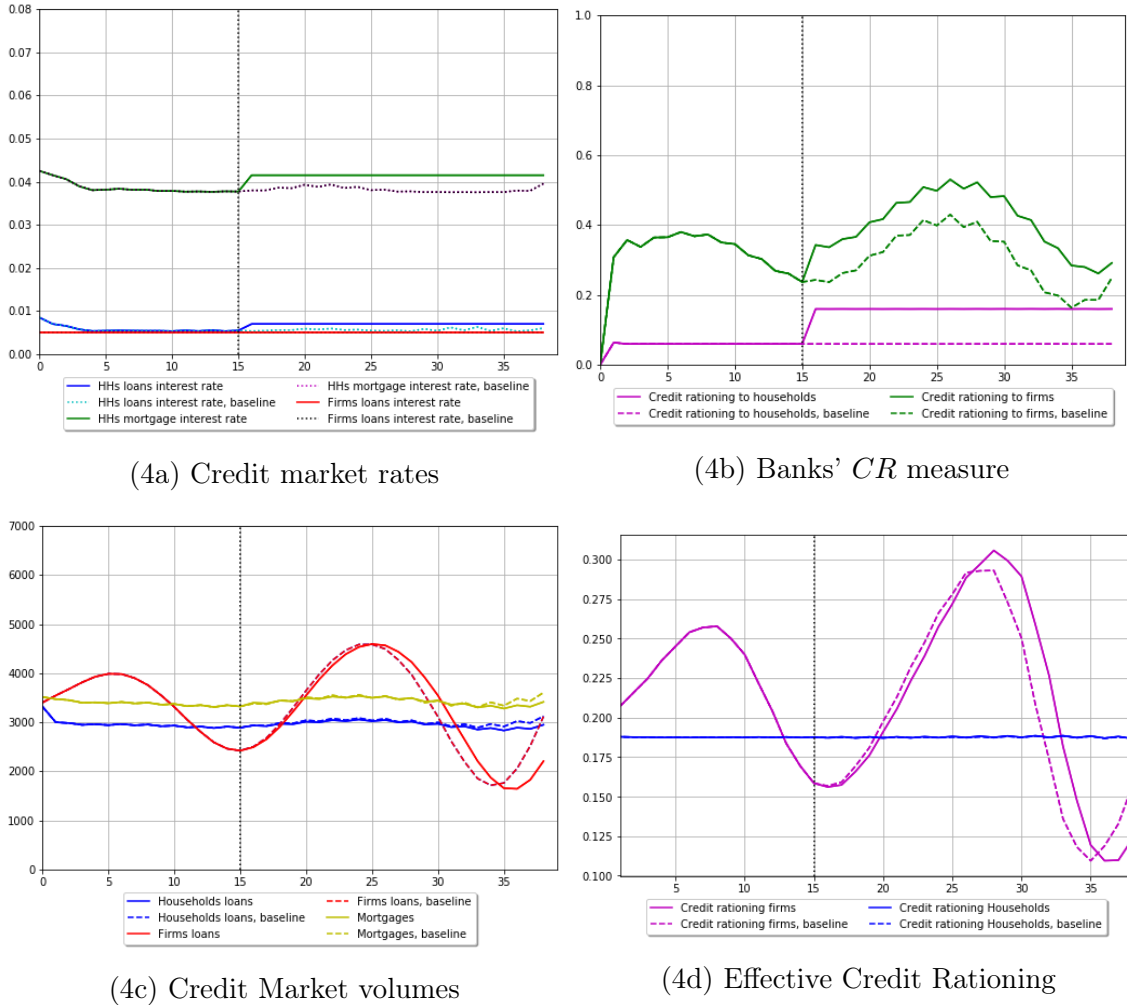
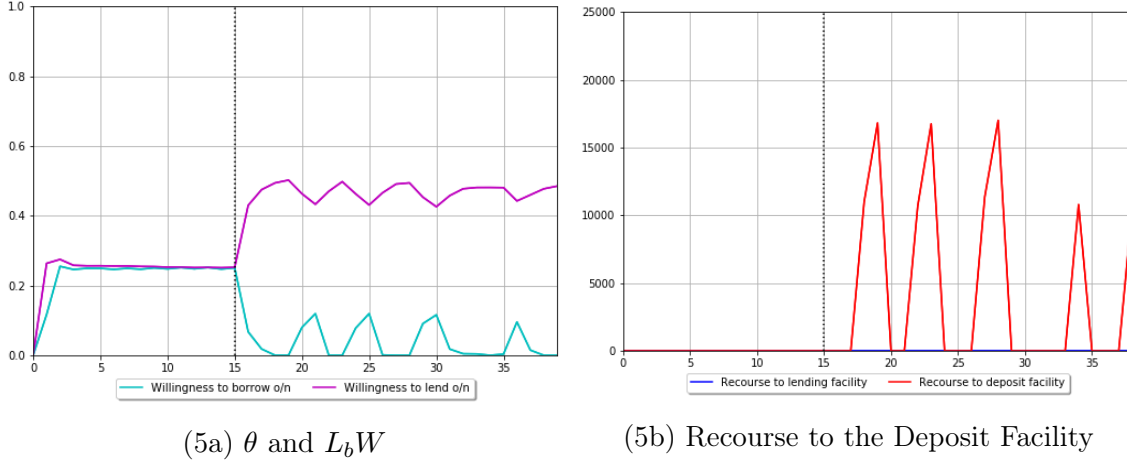


Figure 5: Maximum Degree of Perceived Uncertainty



4.3 Contractionary Monetary Policy

Another experiment conducted in this analysis regards the level of the central bank's policy rates. The system seems to be resilient to monetary policy shocks until the corridor rates are increased by less than 10 basis points. For this reason, figure 6 depicts the evolution of the analyzed economy after a consistent rise of the lending rate from 0.006 to 0.106, and of the deposit one from 0.002 to 0.102. The width of the corridor has been held constant at 0.004.

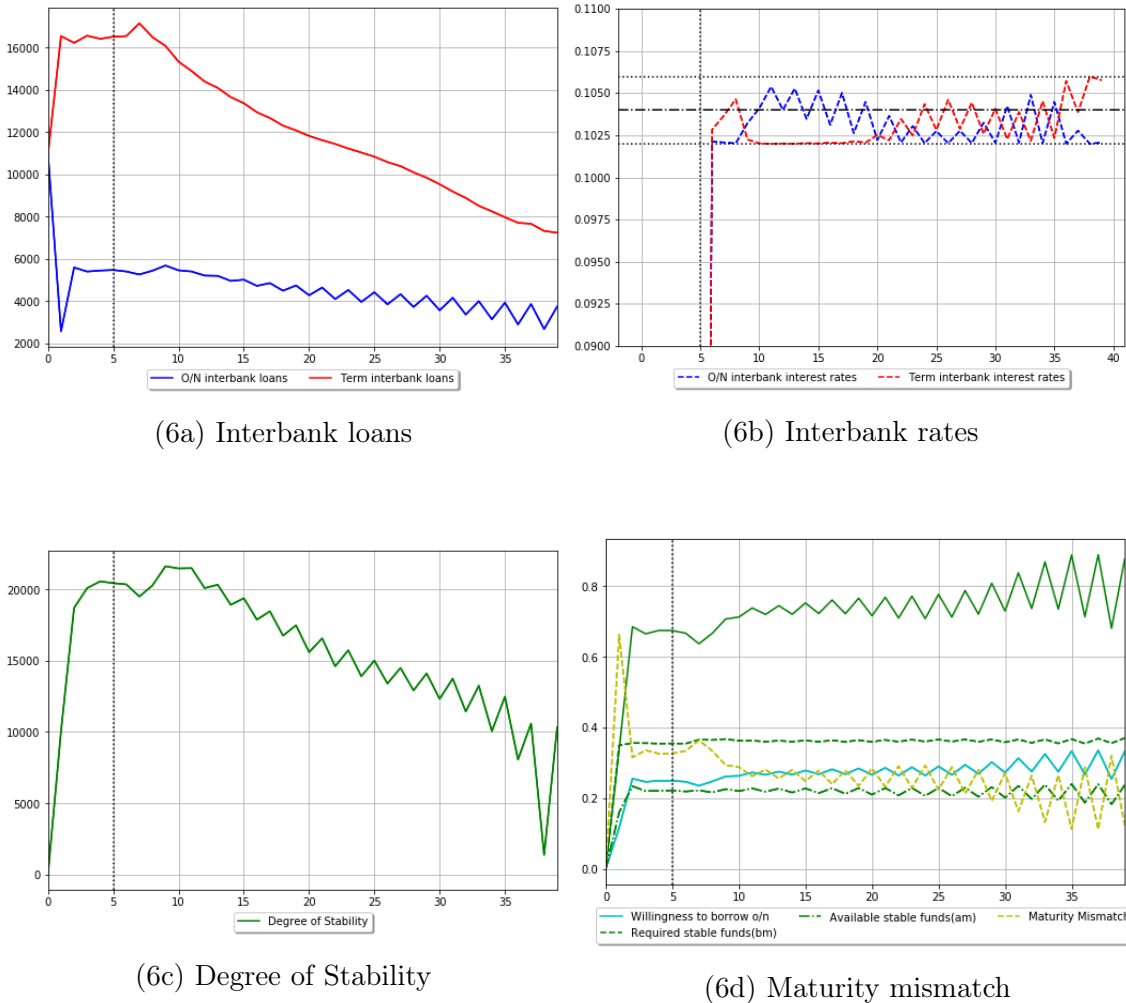
After the shock, the levels of the term excess demand and overnight excess supply appear to be slightly higher than the ones of the baseline scenario, which were almost around zero. This dynamic triggers quite volatile spreads within the new corridor, as it appears from the figures 6(6k)-6(6m).

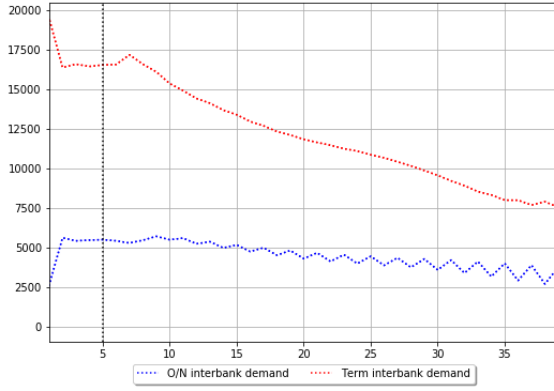
Interbank volumes in the term segment start decreasing at a constant rate over time, following the dynamics of the term interbank demand and supply. Indeed, both banks seem to prefer to borrow and lend overnight over the last periods of the simulations, figure 6(6g), independently of the higher unpredictability of the outside spreads between the overnight rate and the floor one, on the one hand, and between the term rate and the ceiling one, on the other.

The decreasing degree of stability in figure 6(6c) might seem in contradiction with the rising tendency of the same measure when considered within a range between zero and one. However, this divergence is due to the fact that the normalization of the variable has been made by taking the absolute value of bank j 's net worth. Contrary to what happened in the previous scenario, interest payments on the liability side are now increasing, pushing downward the denominator (V_{bj}) which, in absolute value terms, furtherly widens its distance from the origin. Therefore, this increasing tendency showed in figure 6(6d) can be interpreted as illusory, since the decrease in thousand-level corresponds to an increasing distance from zero of the normalized variable. The same reasoning applies to maturity mismatch in the same figure.

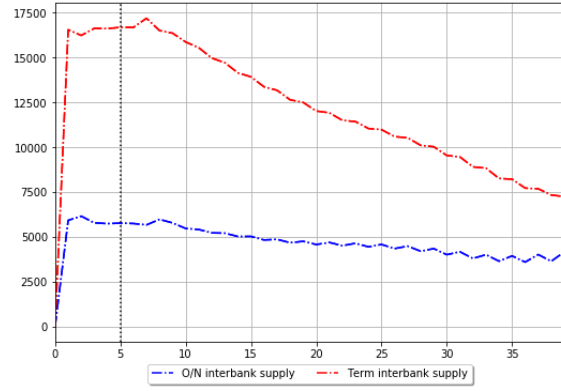
In light of this, what happens to the degree of stability can be better understood by figure 6(6j) which shows the changes in the composition of bank j's assets. The decrease in bank j's degree of stability seems again to be highly influenced by the drop in total liabilities. Despite the changes in the maturity composition of the borrowing bank's balance sheet should not lead to a higher maturity mismatch, because the decrease of term interbank loans in the liability side is compensated by a sharp decline in mortgages and government bonds (figure 6(6i)), the amount of short-term bills is still too high, causing the total required stable funds to maintain its higher level with respect to the available stable funds, figure 6(6d). One possible reason for this dynamic might be detected in the higher rate of interest on bills which is set equal to the target of the central bank, risen from 0.004 of the baseline scenario to 0.104. It would be interesting to see what would happen in the case of a change in the width of the corridor, however, the simulations of this scenario produce problems of convergence.

Figure 6: Dynamics of the interbank market after a monetary policy shock

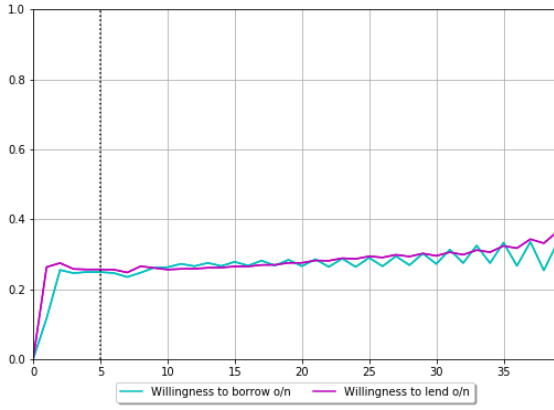




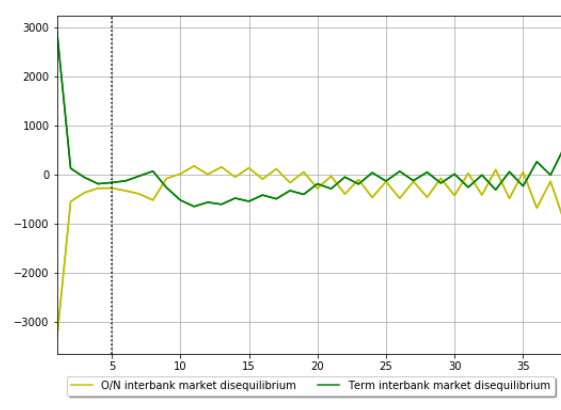
(6e) Interbank demand



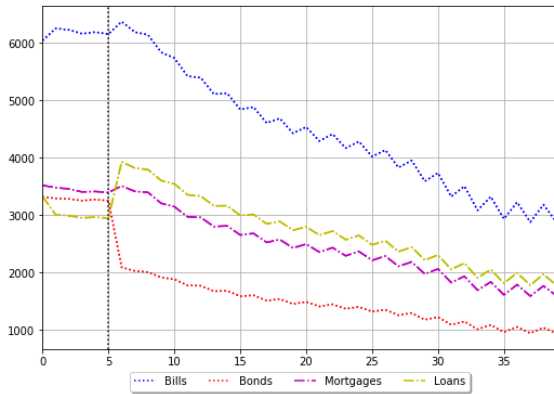
(6f) Interbank supply



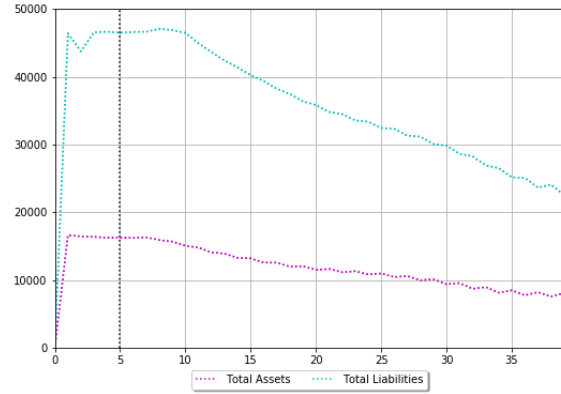
(6g) θ and $L_b W$



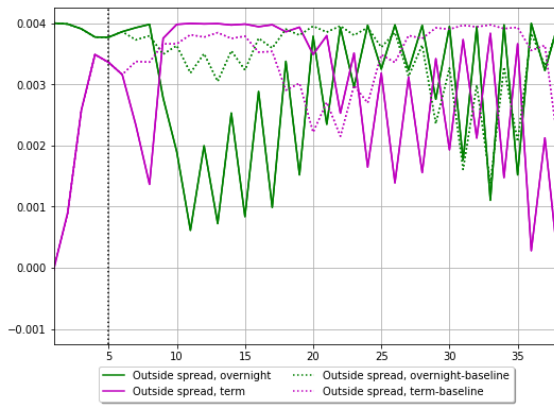
(6h) Interbank disequilibrium



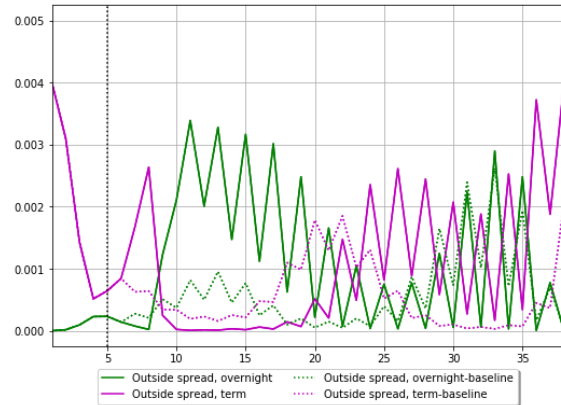
(6i) Bank j ' assets composition



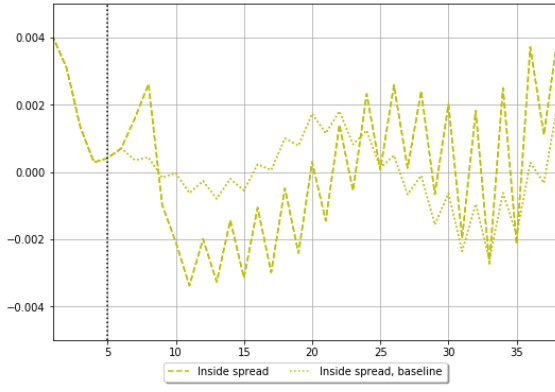
(6j) Bank j 's balance sheet composition



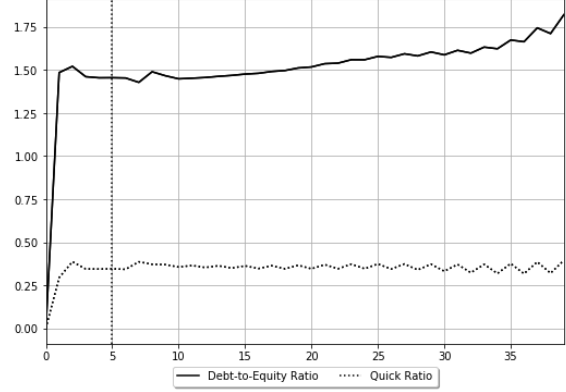
(6k) Borrowing bank outside spreads



(6l) Lending bank outside spreads



(6m) Interbank interest rates spread



(6n) Debt-to-Equity Ratio and Quick Ratio

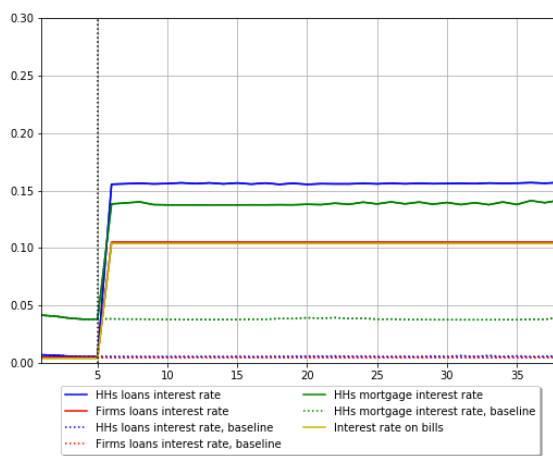
The dynamic process that occurs between a contractionary monetary policy and the credit market is illustrated in figure 7. The central bank's rates hike causes a linear increase of the rates of interest in the credit market, figure 7(7a). This increase of interest rates, combined with the rise of banks' credit rationing (figure 7(7b)), leads to a contraction of loans and mortgages provided to the agents in the real economy. The volumes lent out to households in the form of loans appear clearly lower relative to the baseline scenario only when separated from the overall credit market scenario (figure 7(7d)). Bank k 's extension of loans to firms oscillates at lower levels after period 15.

These effects are the result of the monetary policy transmission mechanism whose channels are depicted in figure 8, following Schasfoort et al. (2017). The credit channel operates via the bank lending channel, on the one hand, and via the balance sheet channel, on the other hand. As regards the former, the rise of the central bank's policy rates leads to a reduction of lending volumes through an upward pressure on banks' funding costs (figure 8(8a)), which follow equation (46) for bank j and the central bank's policy target rate for bank k . Increasing funding costs motivate banks to reduce the quantity of credit, which ultimately affects investments (figure 8(8d)) and consumption (figure 8(8e)). The balance sheet channel describes the influence of changes in monetary policy on credit volumes via the effect of short-term interest rates on agents' net worth. Households' net worth (figure 8(8b)) seems to suffer from a strong downward pressure, decreasing by almost half over the simulation period, after a small hike immediately following the shock. Firms' net worth (figure 8(8c)) exhibits a stronger non-linear variability with respect to the baseline scenario especially over the period 15-20. This seems to be linked to the greater downward trend of net investments in the current scenario, figure 8(8d).

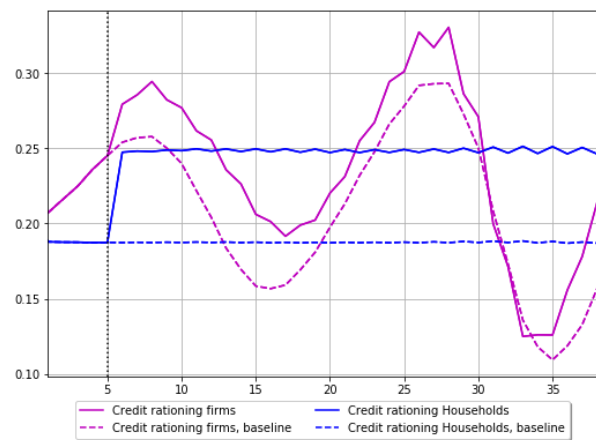
According to the investment channel of monetary policy transmission mechanism, a boost in the rate of interest on firms' loans following the *corridor shock* leads to a consistent drop in firms' desired investments as depicted by the green line in figure 8(8d). This event happens indirectly through interest rates changes, since I_d depends only on real factors in this analysis (see equation 79).

As regards the consumption channel, maintaining constant the exogenous propensities to consume, wealth and income effects (figure 8(8f)) make consumption expenditures less attractive. Moreover, the increasing interest rate on deposits (figure 8(8h)) leads to a rise in households' savings only for a very small period (figure 8(8g)). This might be due to the fact that households' deposits are subject to the trend of the changes in consumption. Last, neither the cost channel nor the consequences on inflation can be analyzed in this context because the price level is set exogenously.

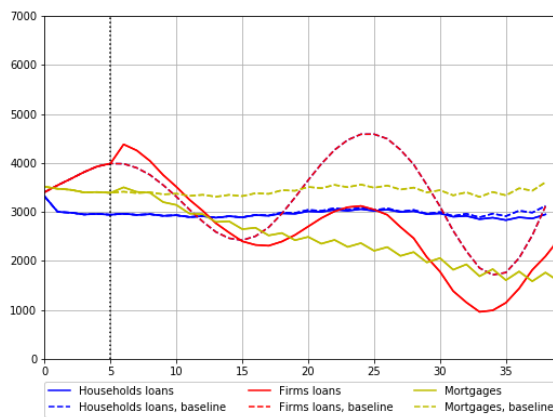
Figure 7: Credit Market dynamics under a monetary policy shock



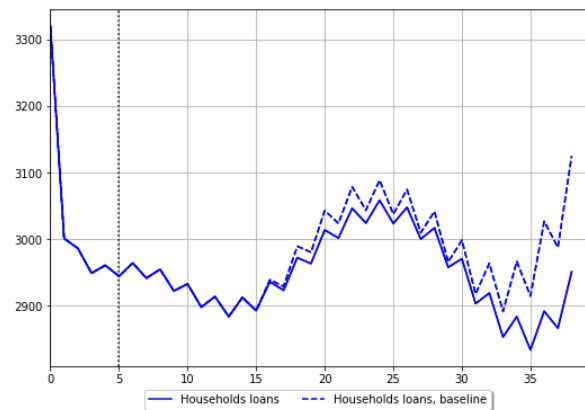
(7a) Credit market rates



(7b) Effective Credit Rationing

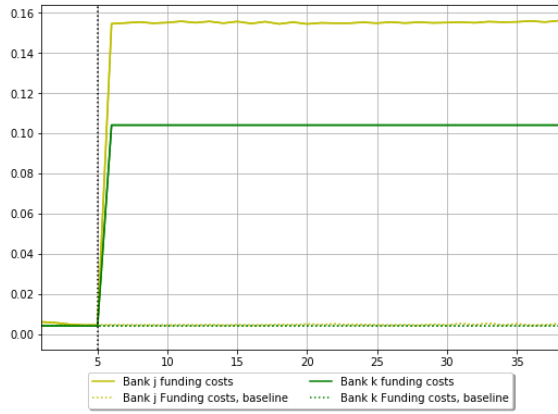


(7c) Credit market volumes

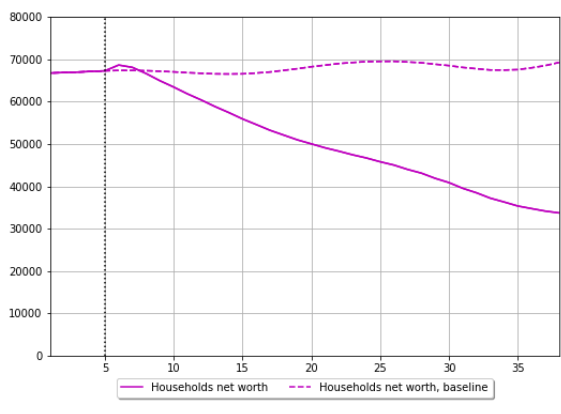


(7d) Households' loans

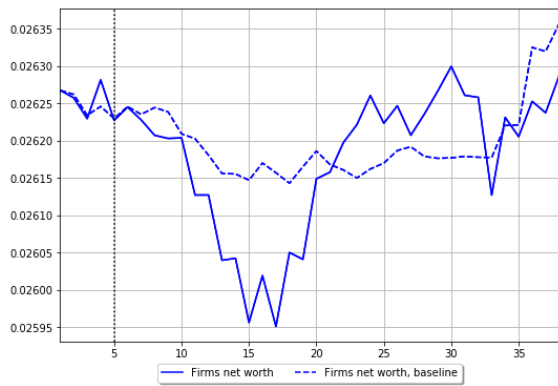
Figure 8: Monetary Policy Transmission Mechanism



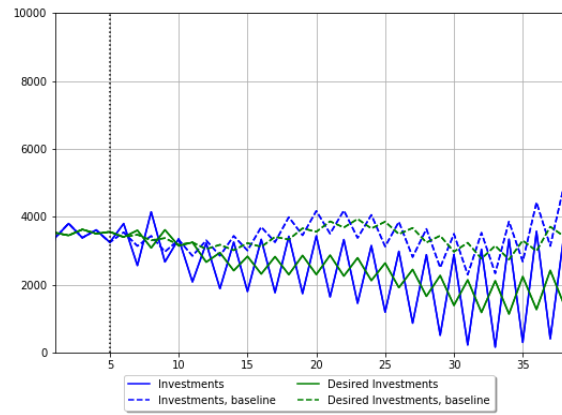
(8a) Banks' funding costs



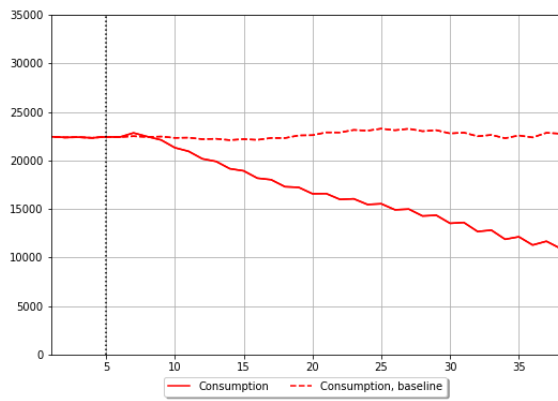
(8b) Households' net worth



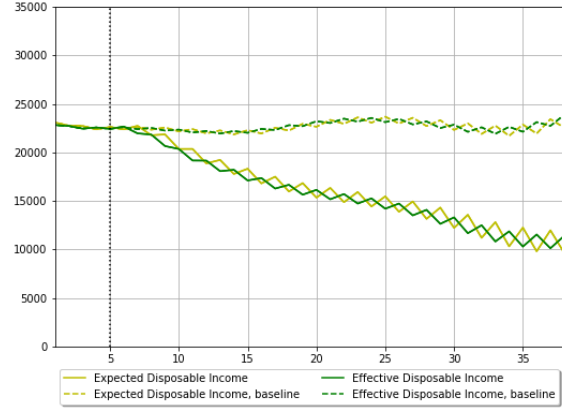
(8c) Firms' net worth



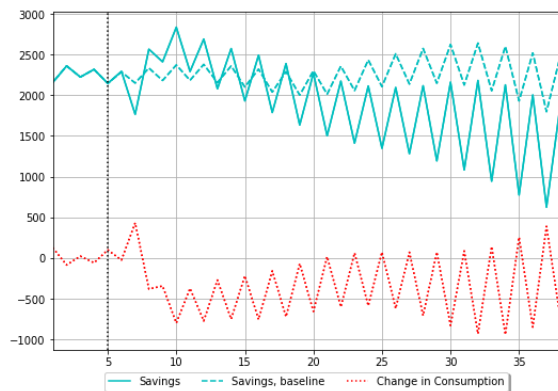
(8d) Firms' investments



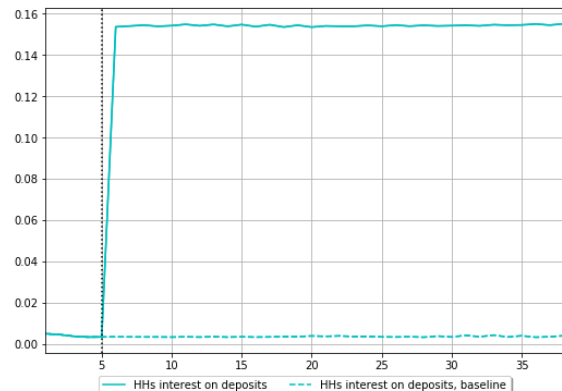
(8e) Households' consumption



(8f) Households' income effect



(8g) Households' savings



(8h) Interest rate on deposits

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; ii) and to incorporate banks' debt structure decisions in terms of maturities as determinants for bilateral interbank transactions.

To do so, banks had to be able to interact both among themselves and with a *more complex* monetary authority. For this purpose, the starting point of this analysis can be identified in the design of a payment system within a monetized production economy. In this context, not only payments translates into deposit flows between banks, and liquidity shocks manifest themselves in the form of deposit outflows, but also fluctuations in payments give birth to a triangular relationship with the central bank, essential to guarantee *immediate settlement activities* through the provision of intra-day credit or overdrafts when needed.

To better capture this event, the banking sector has been considered as composed of two banks: one bank (bank j) providing short-term loans for consumption purposes and mortgages only to households, and the other bank (bank k) granting loans only to firms to finance production. Therefore, whenever households buy consumption goods from firms, the resulting deposit shifts from one bank to the other ensures that banking institutions engage in *reserve management strategies*. Indeed, the bank suffering from a deposit outflow, bank j , needs to repay the central bank for the overdrafts provided in the case its holdings of reserves have not been sufficient for the payment to occur.

On the last day of the reserve maintenance period, bank j has the possibility to ask for reserves to bank k in two segments of the unsecured interbank market: the overnight and the term one. The unique feature of this model is that the borrowing bank's decision about the maturity of the demanded contracts depends on its degree of maturity transformation, or *degree of stability*, which is expressed in terms of the Net Stable Funding Ratio (NSFR) established by Basel III. However, the lending bank can also decide whether to provide overnight or term loans, triggering potential frictions in the interbank market. In the latter case, both banks have the possibility to access the central bank's standing facilities.

The simulations of the model have shown that the volumes exchanged in the interbank market are highly dependent on the inverse maturity mismatch measure constructed. Indeed, both after an increase in the perceived degree of uncertainty and of the central bank's key interest rates, the dynamics of the stocks of interbank loans strictly follow the evolution of bank j 's degree of stability and the composition of its balance sheet, which gives a measure for its degree of maturity transformation. An increase of the stress perceived in the economy leads to an overall reduction of

the volumes exchanged in the interbank market, in accordance to what happened during the last financial crisis, though without necessarily leading the lending bank to hoard liquidity at the central bank. Indeed, the use of the central bank's standing facilities has been almost null in the simulations, apart from the case of maximum uncertainty. This might be due to the strict and simultaneous conditions imposed to the values that banks' willingness to borrow and lend overnight have to assume to access the facilities.

The rise in uncertainty triggered divergent maturity preferences for the banks interacting in the interbank market. As a consequence, the higher disequilibrium dynamics led the spread between the term interbank rate and the overnight one to be at its highest possible levels, given the limits imposed by the central bank's corridor. Despite this, the uncertainty shock provoked to the postulated economy seemed to have had a low pass-through to the credit market, both in terms of interest rates and of credit volumes.

When the economy is hit by a contractionary monetary policy shock, the system is subject to a higher volatility of both the inside spread (between the interbank market rates of interest, term and overnight) and the outside spreads (between the interbank rates and the central bank's corridor rates). In this event, the term interbank volumes suffer from a sharp downward pressure, guided by an increasing preference for overnight loans of both banks in the interbank market. When analysing the monetary policy transmission mechanism, the strength of the balance sheet channel is undeniable. This is linked to the relevant reliance of households and firms on bank credit, on the one hand, and of banks on interbank loans and central bank's overdrafts, on the other hand.

Overall, the constant high levels of maturity mismatch lead the volumes of the overnight segment to be lower relative to the term one, 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, the rates for term interbank loans reach extreme levels, making longer term maturity contracts more expensive and reducing the volumes exchanged in 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, indeed the reduction in the term interbank volumes seems not to be compensated by increasing exchanges in the overnight segment. One possible reason may be detected in the specification of interbank market volumes as strictly dependent on excess supply and excess demand dynamics. Indeed, this does not allow the maturity preferences of the lending bank to be predominant over the ones of the borrowing bank, or vice-versa, as required in this framework to inquire into any potential migration.

Nevertheless, looking at the interbank supply only, it is possible to conclude that as the borrowing bank's funding risk increases, deteriorating its ability to fulfill its debt obligations, the lending bank becomes more willing to reduce its lending maturity preferences even when the overnight interest rate is equal to the floor of the central bank's corridor. Moreover, by assigning a greater power to the lending bank rather than relying on the *short-sides* of the market to determine the final volumes exchanged in the two segments, banks might become more dependent on overnight funding with daily refinancing frequencies, further exacerbating both maturity mismatch and the risk of rollover. As a consequence, this might pose a threat to the desirable balance between discipline and elasticity, both required for a well-functioning money market and for an effective monetary policy transmission mechanism .

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7 Appendix

7.1 Auxiliary tables

Table 6: Implicit contractual maturities and weights

Assets				Liabilities			
	M	RSF	Parameter		M	ASF	Parameter
L_h	$M < 6m$	10%	m_1	D_h		90%	m_5
M_h	$M \geq 1y$	65%	m_2	Ovd	$M < 6m$	0%	
B_j	$6m \leq M \leq 1y$	50%	m_3	MRO_j	$M < 6m$	0%	
B^{lr}	$M \geq 1y$	5%	m_4	IB_{on}	$M < 6m$	0%	
HPM_j		0%		R_{cb}^l	$M < 6m$	0%	
				IB_{term}	$6m \leq M \leq 1y$	50%	m_6

Table 7: Interbank market trades

	$L_bW = 1$	$L_bW = 0$	$0 < L_bW < 1$
$\theta = 1$	IB_{on}^D	IB_{on}^D	IB_{on}^D
	IB_{on}^S	IB_{term}^S	$IB_{on}^S + IB_{term}^S$
$\theta = 0$	IB_{term}^D	IB_{term}^D	IB_{term}^D
	IB_{on}^S	IB_{term}^S	$IB_{on}^S + IB_{term}^S$
$0 < \theta < 1$	$IB_{on}^D + IB_{term}^D$	$IB_{on}^D + IB_{term}^D$	$IB_{on}^D + IB_{term}^D$
	IB_{on}^S	IB_{term}^S	$IB_{on}^S + IB_{term}^S$

Table 8: Parameters and exogenous variables

Symbol	Description	Value
τ	Tax rate on wages	0.18
a_1	Propensity to consume out of income	0.25
a_2	Propensity to consume out of past wealth	0.25
ϕ	Adaptive expectations parameter	0.25
b	Households' loan demand parameter	0.7
p_h	House prices	400
δ_0	Autonomous Housing demand parameter	100
δ_1	Housing demand parameter out of past house prices	0.00125
δ_2	Housing demand parameter out mortgage rate of interest	4
δ_3	Autonomous Mortgage demand parameter	20
δ_4	Mortgage demand parameter out of mortgage rate of interest	0.5
g_k	Desired investments parameter	0.5
ρ	Mark-up on prices	0.4
p	Price level	1
δ	Parameter depreciation of capital	0.5
s	Firms' profit share distributed as dividends	0.6
s_j	Bank j 's profit share distributed as dividends	0.9
s_k	Bank k 's profit share distributed as dividends	0.9
s_w	Parameter for proportion of deposits held at the banks	0.1
m_1	RSF factor on households' Loans	0.1
m_2	RSF factor on Mortgages	0.65
m_3	RSF factor on bank j 's Bills	0.5
m_4	RSF factor on bank j 's bonds	0.05
m_5	ASF factor on households' deposits	0.9
m_6	ASF factor on term interbank loans	0.5
α	Bank j 's sensitivity to outside spread for o/n interbank rate	0.4
α_1	Bank j 's sensitivity to interbank interest rates spread	0.2
α_2	Bank j 's sensitivity to Degree of Stability	0.4
α_3	Bank j 's sensitivity to outside spread for term interbank rate	0.4
α_4	Bank j 's sensitivity to PDU	0.2
i_{cb}^l	Central bank's interest rate on lending facility	0.006; 0.106
PDU	Perceived degree of uncertainty	0.1; 0.6; 1
σ	Bank k 's autonomous willingness to lend o/n	0.1
σ_1	Bank k 's sensitivity to PDU	0.2
σ_2	Bank k 's sensitivity to outside spread for o/n interbank rate	0.4
σ_3	Bank k 's sensitivity to Debt-to-Equity Ratio	0.2
σ_4	Bank k 's sensitivity to interbank interest rates spread	0.4
σ_5	Bank k 's sensitivity to outside spread for term interbank rate	0.1
σ_6	Bank k 's sensitivity to Quick Ratio	0.3
i_{cb}^d	Central bank's interest rate on deposit facility	0.002; 0.102
σ_{ib}	Banks' sensitivity to interbank market disequilibrium	0.01
η_1	Floor rate for the term interbank rate	0
η_2	Width of the corridor for the term interbank rate	0.006
ω_1	Banks' sensitivity to PDU for Credit Rationing	0.2
ω_2	Banks' sensitivity to past loans for Credit Rationing	0.3
χ_1	Mark-up on loan interest rates in the credit market	0.001
χ_2	Mark-down on deposit interest rates in the credit market	0.001
χ_3	Mark-up on mortgage interest rate	0.0355
μ	Reserve Requirement	0.2
i_b^{lr}	Rate of interest on bonds	0.0269
γ	Debt-to-equity threshold	1

Table 9: Parameters and exogenous variables-continued

Symbol	Description	Value
λ_{10}	Bank j 's parameter for liquidity preferences loans	0.2
λ_{11}	Bank j 's parameter for liquidity preferences out of loans rate of interest	0.6
λ_{12}	Bank j 's parameter for liquidity preferences out of bonds rate of interest	0.3
λ_{13}	Bank j 's parameter for liquidity preferences out of mortgage rate of interest	0.2
λ_{14}	Bank j 's parameter for liquidity preferences out of bills rate of interest	0.1
λ_{20}	Bank j 's parameter for liquidity preferences bonds	0.2
λ_{21}	Bank j 's parameter for liquidity preferences out of loans rate of interest	0.3
λ_{22}	Bank j 's parameter for liquidity preferences out of bonds rate of interest	0.6
λ_{23}	Bank j 's parameter for liquidity preferences out of mortgage rate of interest	0.2
λ_{24}	Bank j 's parameter for liquidity preferences out of bills rate of interest	0.1
λ_{30}	Bank j 's parameter for liquidity preferences mortgages	0.2
λ_{31}	Bank j 's parameter for liquidity preferences out of loans rate of interest	0.3
λ_{32}	Bank j 's parameter for liquidity preferences out of bonds rate of interest	0.2
λ_{33}	Bank j 's parameter for liquidity preferences out of mortgages rate of interest	0.6
λ_{34}	Bank j 's parameter for liquidity preferences out of bills rate of interest	0.1
β_{10}	Bank k 's parameter for liquidity preferences	0.2
β_{11}	Bank k 's parameter for liquidity preferences out of loans rate of interest	0.3
β_{12}	Bank k 's parameter for liquidity preferences out of bills rate of interest	0.1
<hr/>		
g_{ss}	SS Nominal rate of growth	0.0075
θ_0	SS willingness to borrow o/n	0.5
i_{h0}^d	SS interest on deposits for households	0.0065
i_{h0}^l	SS interest on loans for households	0.0085
i_{h0}^m	SS interest on mortgages	0.0425
i_{f0}^l	SS interest on loans for firms	0.005
i_{f0}^d	SS interest on deposits for firms	0.003
CR_{h0}	SS Credit Rationing on households	0.005
CR_{f0}	SS Credit Rationing on firms	0.005
i_{ib0}^{on}	SS o/n interbank rate	0.004
i_{ib0}^{term}	SS term interbank rate	0.007
i_{cb0}^t	SS target policy rate	0.004
i_{b0}	SS bills interest rate	0.004

Table 10: Initial Values-Balance Sheet Matrix

	Households	Firms	Government	Central Bank	Banks		Σ
					Bank j	Bank k	
Capital stock (K)		+7062.3364					+7062.3364
Houses (H)	+39733, 48						+39733, 48
Deposits (D)	+2143.3681	+2313.1847			-2143.3681	-2313.1847	0
Loans (L)	-3320.4279	-3403.7153			+3320.4279	+3403.7153	0
Mortgages (M)	-3515.3187				+3515.3184		0
Bills (B)			-22430.8679	+2803.6041	+6037.8922	+13589.3715	0
Bonds (B_j^{lr})			-3313.30572		+3313.30572		0
Overdrafts (Ovd)				+21916.5145	-21916.5145		0
Required Reserves (HPM)				-884.6755	+425.4825	+459.1930	0
Overnight Interbank Loan (IB_{on})					-10958.2572	+10958.2572	0
Term Interbank Loan (IB_{term})					-10958.2572	+10958.2572	0
Main Refinancing Operations (MRO)				+884.6755	-425.4825	-459.1930	0
Lending Facility Reserves (R_{cb}^l)				+0	-0		0
Deposit Facility Reserves (R_{cb}^d)				-0		+0	0
Net Wealth: Σ	+35041, 1015	+5971, 8058	+(25744, 17362)	+24720, 1195	+(29789, 45278)	+36596, 4165	+46795, 8164

Table 11: Initial Values-Transaction Flow Matrix

Operation	Household	Firm		Banks				Central Bank			Σ
		Current	Capital	Bank j		Bank k		Current	Capital	Government	
				Current	Capital	Current	Capital				
Consumption	-22338.8296	+22338.8296									0
Government Expenditure		+3864.4033								-3864.4033	0
Investments		+3557, 4548	-3557, 4548								0
Housing Investments	-295, 7827	+295, 7827									0
Wages	+21468.9076	-21468.9076									0
Taxes	-3835, 6361									+3835, 6361	0
Interest on Bills				+23, 9717		+53, 9498		+11, 1303		-89, 0505	0
Interest on Bonds				+88, 4594						-88, 4594	0
Interest on Loans	-27, 8018	-16, 7623		+27, 8018		+16, 7623					0
Interest on Deposits	+13, 7236	+6, 8358		-13, 7236		-6, 8358					0
Interest on Mortgages	-147, 1684			+147, 1684							0
Interest on IB_{on}				-43, 1779		+43, 1779					0
Interest on IB_{term}				-75, 5614		+75, 5614					0
Interest on MRO				-1, 6891		-1, 8229		+3, 5121			0
Interest on Lending Facility				-0				+0			0
Interest on Deposit Facility						+0		-0			0
Profits of firms	+5324, 0051	-8873.34188	+3549, 3367								0
Profits of bank j	+138, 2199			-153.5776	+15, 3577						0
Profits of bank k	+163, 5995					-181.7772	+18, 1777				0
Profits of CB								-14, 6432		+14, 6432	0
Δ Deposits	-15, 9555		-17, 2197		+15, 9555		+17, 2197				0
Δ Loans	+24, 7178		+25, 3378		-24, 7178		-25, 3378				0
Δ Mortgages	+26, 1680				-26, 1680						0
Δ Bills					-44, 946		-101, 1592		-20, 87	+166, 9753	0
Δ Bonds					-24, 6642					+24, 6642	0
Δ HPM					-3, 1672		-3, 4182		+6, 5855		0
Δ MRO					+3, 1672		+3, 4182		-6, 5855		0
Δ Advances					+163, 1465				-163, 1465		0
Δ IB_{on}					+81, 5732		-81, 5732				0
Δ IB_{term}					+81, 5732		-81, 5732				0
Δ Lending Facility					+0				-0		0
Δ Deposit Facility							-0		+0		0
Δ Net Worth	498, 1674	-278, 94328	-0	-0, 3283	237, 11017	-0, 9845	-254, 246	-0, 0008	-184, 0165	0, 0056	0
Σ	0	0	0	0	0	0	0	0	0	0	0

7.2 Demonstrations

Demonstration of well-behaved demand and supply functions.

The derivative of the overnight demand for interbank loans must be negative with respect to the overnight interest rate; and the derivative of the term demand for interbank loans must be negative with respect to the term interest rate.

Taking equation (18), and substituting equation (20), it is possible to denote with v all the elements that do not include the overnight interest rate as follows:

$$v = \bar{\alpha}_2 DS_m - \bar{\alpha}_3(\bar{i}_{cb}^l - i_{ib}^{term}) - \bar{\alpha}_4 \overline{PDU} \quad (h)$$

Hence, IB_{on}^D can be re-written as

$$IB_{on}^D = IB^D[\bar{\alpha}(\bar{i}_{cb}^l - i_{ib}^{on}) + \bar{\alpha}_1(i_{ib}^{term} - i_{ib}^{on}) + v] \quad (l)$$

It is immediately possible to see that the $\frac{\partial IB_{on}^D}{\partial i_{ib}^{on}} < 0$. When taking into account the term demand, the same strategy can be applied, and by defining:

$$v_1 = \bar{\alpha}(\bar{i}_{cb}^l - i_{ib}^{on}) + \bar{\alpha}_2 DS_m - \bar{\alpha}_4 \overline{PDU} \quad (m)$$

it is possible to get:

$$IB_{term}^D = IB^D[1 - \bar{\alpha}_1(i_{ib}^{term} - i_{ib}^{on}) + \bar{\alpha}_3(\bar{i}_{cb}^l - i_{ib}^{term}) - v_1] \quad (n)$$

Therefore, also in this case $\frac{\partial IB_{term}^D}{\partial i_{ib}^{term}} < 0$.

About the lending bank's supply function, let us take equation (23) and substitute equation (25). After denoting with v_2 all the elements not including the overnight interest rate,

$$v_2 = \bar{\sigma} + \bar{\sigma}_1 \overline{PDU} + \bar{\sigma}_3(|DER_j| - \gamma) - \bar{\sigma}_5(i_{ib}^{term} - \bar{i}_{cb}^d) - \bar{\sigma}_6 QR \quad (o)$$

we get

$$IB_{on}^S = IB^S[v_2 + \bar{\sigma}_2(i_{ib}^{on} - \bar{i}_{cb}^d) - \bar{\sigma}_4(i_{ib}^{term} - i_{ib}^{on})] \quad (q)$$

from which it is possible to assess that $\frac{\partial IB_{on}^S}{\partial i_{ib}^{on}} > 0$.

Adopting the same rationale, and defining v_3 as in equation (r), it is possible to demonstrate that bank k 's term supply function is also increasing with respect to the term interest rate.

$$v_3 = \bar{\sigma} + \bar{\sigma}_1 \overline{PDU} + \bar{\sigma}_2(i_{ib}^{on} - \bar{i}_{cb}^d) + \bar{\sigma}_3(|DER_j| - \gamma) - \bar{\sigma}_6 QR \quad (r)$$

$$IB_{term}^S = IB^S[1 - v_3 + \bar{\sigma}_4(i_{ib}^{term} - i_{ib}^{on}) + \bar{\sigma}_5(i_{ib}^{term} - \bar{i}_{cb}^d)] \quad (s)$$

Therefore, also $\frac{\partial IB_{term}^S}{\partial i_{ib}^{term}} > 0$, and all the conditions are satisfied, both from the demand side, and from the supply side. QED