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Banks, money and the zero lower bound

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Banks, money and the zero lower bound

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Abstract

We study a New Keynesian model where banks create deposits through loans, subject to increasing marginal cost of lending. Banks do not intermediate commodity deposits between savers and borrowers, instead they offer a payment system that intermediates ledger-entry deposits between different spenders. We discuss three implications. First, non-banks' aggregate purchasing power consists not only of their income but also of new loans/deposits. Second, near the ZLB policy rate reductions compress spreads, and thereby reduce bank profitability, deposit creation and output. Third, near the ZLB Phillips curves are flatter, because lower factor cost inflation is partly offset by inflationary credit rationing.

Key words: Banks, financial intermediation, endogenous money creation, bank loans, bank deposits, money demand, deposits-in-advance, Phillips curve, zero lower bound, monetary policy rules.

JEL classification: E41, E44, E51, G21.

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1. Introduction

This paper is a contribution to the post-GFC literature on the role of banks in the macro-economy. As argued in Benes and Kumhof (2012), Jakab and Kumhof (2015, 2018) and Faure and Gersbach (2017), this literature has been using, almost without exception, “intermediation of loanable funds” (ILF) models, where banks are intermediaries between savers and borrowers. As we will discuss, in such models banks need to first collect deposits of commodities, and in some cases also of capital, from savers before they can lend those commodities to borrowers. These models are fundamentally non-financial, because banks are essentially warehouses that store, borrow and lend commodities, and whose liabilities are commodity money. While at the microeconomic or corporate finance level the financial intermediaries of ILF models can be a very useful representation of non-bank financial institutions (NBFIs) that intermediate existing funds between different agents, at the macroeconomic level neither do NBFIs intermediate commodities - they intermediate financial balances, typically bank liabilities - nor do bank loans intermediate existing funds - they create new funds. The aim of the present paper is therefore to replace the non-financial ILF model with a financial “financing through money creation” (FMC) model, and to study some of the macroeconomic implications. Moreover, unlike in the FMC model of Jakab and Kumhof (2015, 2018), where a representative household interacts with banks subject to a transactions cost technology, here we explicitly model the economic exchanges between different agents that require the use of bank deposits. In this model banks are indeed intermediaries, but between multiple spenders of money rather than between savers and borrowers of commodities. Critically, FMC models do not propose to challenge and replace but rather to use the many advances that have been made in the modelling of financial institutions themselves, because the crucial difference between ILF and FMC models is not found in the optimisation problems of financial institutions but in the budget constraints, or rather the deposits-in-advance constraints, of their customers.

To demonstrate why deposit-taking and lending in ILF models represents real rather than financial transactions, we study a typical deposit transaction. Assume that A, who has an account at Bank A, has performed a service for B, who has an account at Bank B. In return A receives a check drawn on B’s account, and deposits it in Bank A. The critical observation is that this check only has value *because the deposit already exists* - in Bank B. The transaction simply moves an existing deposit to a different account within the banking system, it does not create a new deposit for the banking system. Furthermore, it does not give Bank A additional funds to lend, because by double-entry bookkeeping the new deposit is automatically lent to Bank B at the moment it is received, in the form of an accounts receivable claim for the collection of funds in the form of central bank reserves. The same logic applies to any deposit of private financial instruments into bank accounts - they are not loanable funds, and they are not new funds. Central bank money (reserves or cash) deposited in banks does not represent loanable funds either, because central bank reserves cannot be lent to non-banks, only to other banks, while physical cash is never disbursed against new bank loans, only against preexisting electronic deposits.¹ But the only items that are ever deposited into bank accounts are private financial instruments and central bank money. What then is the meaning of deposit-taking and lending in ILF models? The answer is that they always represent the physical accumulation of commodities, in some cases augmented by the physical accumulation of capital (or of securities that represent claims to capital). This can be seen very clearly in the budget constraints of banks’ depositors

¹Overdrafts are not an exception. An overdraft represents the creation of a new bank deposit on demand. This deposit can then be instantaneously withdrawn in the form of a check or cash.

(and borrowers) in these models. In the most common budget constraint changes in deposits equal the difference between physical income and physical spending, a difference that represents the physical accumulation, and then intermediation by way of bank loans, of commodities. Banks are therefore warehouses, and because bank deposits are always at least in part created via the physical accumulation of commodities, they represent commodity money. The accumulation of physical capital augments but does not fundamentally change this model, and furthermore, as discussed below, it plays only a very small role in aggregate banking system data.

In FMC models banks are financial institutions rather than warehouses, and money is an accounting entry in the books of financial institutions rather than a commodity. When it makes a new loan to customer X, a bank simultaneously creates a new loan entry, in the name of X, on the asset side of its balance sheet, which represents its right to receive future installments and interest on the loan, and a new and equal-sized deposit entry, also in the name of X, on the liability side of its balance sheet, which represents its obligation to deliver current funds. The key observation is that in the case of banks this newly-created “accounts payable” liability (IOU) to deliver current funds can immediately be used *as* current funds, as money. Only banks are able to do this, because only banks are perceived to be able to credibly commit to honouring their IOUs universally (that is, vis-à-vis any subsequent holder of the IOU), thereby making these IOUs acceptable as a universal medium of exchange. Part of the literature has argued that banks have this ability because of their ability to diversify and thereby privately construct optimal portfolios of liabilities that are perceived to be safe, or at least much safer than the alternatives. We would argue that while this private mechanism is indeed present and plays an important role, explicit and implicit public support for banking systems is even more important, especially during crisis times, with the quality of banks’ assets often only determining the fiscal cost of public support operations. In fact, the entire system of central banks and regulatory agencies has been constructed with this as its main objective, because trust in the nation’s main medium of exchange is considered critical for the performance of the entire economy. The implicit assumption in our model is that this public guarantee is exclusive to banks and is perceived to be completely credible, so that bank loans and bank deposits are risk-free, and bank deposits are the only circulating medium of exchange. This moves the emphasis away from bank asset-side considerations to an exclusive liability-side focus, in other words to an exclusive focus on the monetary dimension of banks’ activity.

There is another way of stating the difference between ILF and FMC models in terms of balance sheets. Banks in the ILF model record nonzero net non-financial (physical) transactions, which means that *loans are conditional on deposits* that are created through the saving of physical resources, and where loans represent an exchange of two physical bank assets, existing warehoused commodities against a repayment claim for future delivery of commodities. This notion is one of barter of different commodities against each other, and as such it originates in thinking of banks analogously to non-financial firms. Banks in the FMC model record nonzero gross, but zero net, financial (monetary) transactions, which do not require prior saving of physical resources, and where loans represent the creation of new financial assets that are funded by the simultaneous creation of new financial liabilities, new deposits against a repayment claim for future delivery of deposits. In other words, *deposits are conditional on loans* that are created through ledger entries. The bank’s customer experiences no impact change in his net balance sheet position vis-à-vis the bank, but such transactions are nevertheless essential for the functioning of the real economy, because the new bank liability represents an addition to the economy’s stock of money. But while this money facilitates purchases and sales of physical

resources outside the banking system, it is not itself a physical resource, and can be created at negligible resource cost. Money and commodities circulate on two separate circuits, while the ILF model, which is based on the notion of commodity money, conflates these two circuits.

The foregoing discussion illustrates that accounting is an indispensable tool for understanding the economics of money and banking. The activity of banks consists almost entirely of the profit-maximising and risk-minimising creation and destruction of ledger entries.² To understand how these ledger entries are created, one has to understand accounting, because accounting is the technology of banking.

The clearest explanations of the money creation process, which make exactly the same arguments as in this paper, come from two reports by the Bank of England (McLeay et al. (2014a,b)), from a number of papers by the Bank for International Settlements (see e.g. Borio and Disyatat (2011, 2015)), and from a report by the Bundesbank (Bundesbank (2017)). FMC models are now also beginning to find their way into the DSGE models of central banks and policy institutions, including the International Monetary Fund (Benes et al. (2014a,b)), the Central Bank of Ireland (Lozej et al. (2017), Lozej and Rannenberg (2017)), Norges Bank (Kravik and Paulsen (2017)) and People's Bank of China (Sun and He (2018)).

The creation and destruction of credit and money through profit-maximising double-entry bookkeeping entries that is at the core of the FMC model also provides a very natural explanation for the observed very large and rapid quarter-on-quarter changes in aggregate banking sector balance sheets documented in Jakab and Kumhof (2015, 2018). These authors discuss that ILF models, in order to rationalise these observations, must rely on a combination of three mechanisms, first the accumulation of physical commodities (real savings), second the accumulation of physical capital or of securities that represent claims to physical capital (substitution between direct and indirect/bank holdings), and third valuation effects on asset portfolios. They demonstrate that these mechanisms play only a very small role in aggregate financial system data of major developed economies.

It is important to emphasise that when we refer to banks, bank loans and bank deposits, both conceptually and in our formal model, we are thinking of the institutions, assets and liabilities of the entire financial system, which includes both banks and NBFIs. As shown in Pozsar (2014), modern NBFIs are not creators of money but intermediaries of bank-created money. Banks are the central actors in the overall financial system, because their ability to create new money implies that the system as a whole has the ability to create new money, even if a subset of institutions only has the ability to use but not to create such money. It is therefore legitimate to model the overall financial system as consisting entirely of banks, but not to model it as consisting entirely of NBFIs.

This paper introduces a bank-based monetary transactions mechanism, where bank deposits have to be used to make all of the economy's payments, into an otherwise standard macroeconomic environment. It does so by using a sequence of deposits-in-advance constraints.³ Simplifying for the purpose of exposition⁴, inside each period loans are made to firms in order to create deposits.

²This was expressed very clearly by Milton Friedman (1971, p. 2): "The correct answer for [the question of the origin of] both Euro-dollars and liabilities of US banks is that their major source is a bookkeeper's pen."

³Our deposits-in-advance constraint is akin to the cash-in-advance constraint, whose origins can be traced at least as far back as Clower (1967). Other prominent examples of models with cash-in-advance constraints include Grandmont and Younes (1972), Lucas and Stokey (1987), Dubey and Geanakoplos (2003) and Tsomocos (2003).

⁴We abstract from payments to and from banks (interest) and government (taxes, spending and bond purchases).

The deposits are used to make two sets of successive payments. The first is payments for wages, user costs and profit distributions from firms to households to pay for the production of output, and the second is payments from households to firms to pay for the sale of output, with the second set of payments extinguishing the loans. Because of the intra-period nature of this sequence, it remains compatible with Jakab and Kumhof (2015, 2018), which merges workers and firms into a single representative worker-firm in the spirit of Lucas (1990) and Schmitt-Grohé and Uribe (2004), and where the multiple deposits-in-advance constraints are replaced by a single transactions cost technology.

This approach demonstrates clearly why bank financing is so critical. Non-bank agents in our FMC model are not constrained by a budget constraint that limits their purchasing power to their income, but instead by a deposits-in-advance constraint that limits their purchasing power to the sum of their income and net new deposit creation. Income can be used to make purchases because it is received in the form of bank deposits that are generally accepted in payment. But bank deposits can also be created through additional loans, independently of prior income flows. By contrast, in ILF models the debt-financed increase in the purchasing power of the borrower is offset by the diminished purchasing power of the lender, because a finite stock of commodities changes hands between them, through the agency of banks. Our description of the FMC model does of course not imply that banks allow agents to violate the economy's overall resource constraint. Rather, the creation of additional deposits permits a mobilisation of additional resources that increases income, especially when the economy is financially constrained.

Our model studies the implications of a specific financial constraint, the zero lower bound (ZLB) on deposit interest rates, in part by comparing the behaviour of the ZLB-constrained economy to that of an otherwise identical unconstrained economy. In the unconstrained economy deposit interest rates adjust to achieve the spread that banks require in order to cover the cost of making loans, so that loans respond highly elastically to changes in credit demand. At the ZLB deposit interest rates can no longer adjust, and any change in the policy rate, which determines banks' lending rates, leads to a change in spreads that changes their ability to cover the cost of making loans, and therefore to a change in the creation of credit and deposits. In this case loans are unresponsive to changes in credit demand.

In this ZLB-constrained environment higher policy interest rates are, *ceteris paribus*, expansionary. Specifically, because banks' profit margins depend on nominal interest rate spreads, a permanent increase in the nominal policy rate that does not depart from the fundamental level of real interest rates, in other words a higher level of steady state inflation, implies a permanent expansion in credit, deposits and output. Similarly, policies that give rise to a temporary increase in inflation and thereby (via a monetary policy rule) in policy rates are, *ceteris paribus*, expansionary. The economy therefore behaves in a highly monetarily non-neutral way, both in the short term and the long term. Of course the argument that higher inflation can help to get an economy out of a deep recession is not new, but our transmission mechanism, from inflation to spreads to deposit creation to economic exchange to real activity, is new.

Furthermore, in the ZLB-constrained environment the drivers of inflation include not only traditional marginal cost terms, consisting of wages and user costs, but also the multiplier of a credit rationing constraint. Based on our empirical estimates, the supply of credit is highly responsive to interest rate spreads, and this means that contractionary shocks, if accompanied by a drop in the policy rate, tend to lead not only to a drop in traditional marginal cost terms but also to tighter credit rationing. The latter, *ceteris paribus*, tends to have an inflationary rather

than a deflationary effect, because credit rationing induces producers to charge higher prices, even if they expect this to be at the expense of losing market share, because higher sales revenue allows them to relax their credit rationing constraint. This offsetting effect implies that the inflation response to shocks near the ZLB is much more subdued than away from the ZLB, while the output response is significantly amplified by credit rationing. In other words, the Phillips curve is much flatter near the ZLB.

The rest of the paper is organised as follows. Section 2 reviews the related theoretical and empirical literatures. Section 3 presents empirical evidence on the elasticity of credit supply with respect to lending spreads. Section 4 develops our theoretical models, one unconstrained model and one ZLB-constrained model. Section 5 studies illustrative simulations based on these models. Section 6 concludes.

2. Literature Review

In this section we review four strands of literature that are related to our paper. Section 2.1 reviews the recent theoretical macro literature on banking. Section 2.2 reviews the literature on the distinction between income and purchasing power. Section 2.3 reviews the literature on contractionary reductions in nominal policy interest rates near the ZLB. Section 2.4 reviews the literature on flat Phillips curves near the ZLB.

2.1. The Theoretical Macro Literature on Banking

In this section we review the recent theoretical macro literature on banking.⁵ For convenience we divide our review into two parts, New Keynesian DSGE models and other macroeconomic theory models.

2.1.1. New Keynesian DSGE Models

In relation to our paper, recent DSGE models with financial frictions can be divided into three groups. In the first group, all lending is direct and in the form of physical commodities (or capital). Because banks are absent, this literature is distant from the topic of this paper. It includes Iacoviello (2005), which uses the borrowing constraint first introduced by Kiyotaki and Moore (1997), and Jermann and Quadrini (2012). In the second and third groups, banks are present, but lending is also in the form of physical commodities. In the second group, banks' net worth and balance sheets play no role in the analysis, typically because all lending risk is diversifiable and the emphasis is on loan pricing. This group includes Christiano et al. (2014), which uses the costly state verification mechanism first introduced into macro models by Bernanke et al. (1999), as well as Cúrdia and Woodford (2010), de Fiore et al. (2011) and Boissay et al. (2016). In the third group, banks' balance sheets and net worth do play a role, either through an incentive constraint under moral hazard or through a regulatory constraint. This group includes Gerali et al. (2010), Gertler and Karadi (2011), Gertler and Kiyotaki (2011), Adrian and Boyarchenko (2013), Clerc et al. (2015), Nelson et al. (2015), Justiniano et al. (2015), Benes and Kumhof (2015), Eggertsson et al. (2017) and Nuño and Thomas (2017).

⁵An older literature on the credit channel view of monetary policy is summarised in Kashyap and Stein (1993) and Kashyap et al. (1993). This paper will not discuss partial equilibrium corporate finance models of banking.

2.1.2. Other Macroeconomic Theory Models

We classify models in this group by the three main mechanisms for aggregate bank balance sheet growth that have been identified in the literature. The first mechanism is the ex-nihilo creation or destruction of ledger entries (FMC), the second is the acquisition, sale or revaluation of existing physical assets or of securities that represent claims to such assets (SEC), and the third is the saving of physical commodities (SAV). Other than our own previous work (Benes and Kumhof (2012), Jakab and Kumhof (2015, 2018)) and the related work at central banks cited in Section 1, to our knowledge only two papers, Goodfriend and McCallum (2007) and Faure and Gersbach (2017), are based exclusively on the FMC mechanism. In Goodfriend and McCallum (2007) loans create deposits that enter a cash-in-advance constraint on consumption. Because the model features a real loan production function, impulse responses for financial shocks have a stronger real flavour than in other FMC models. Faure and Gersbach (2017), in a 2-period model, show that in the absence of uncertainty ILF and FMC models imply identical allocations. This is related to the result in Jakab and Kumhof (2015, 2018) that the deterministic steady states of the two model classes are identical. The three-period model of Donaldson et al. (2018), a 3-period model, is based on a combination of the FMC and SAV mechanisms for balance sheet growth. As in FMC models, banks issue book money (“fake receipts”) through risky lending. But as in ILF models, banks also need to function as warehouses that issue commodity money (“commodities receipts”), because warehoused commodities are required as collateral. The paper has at its heart an excellent explanation of the ability of banks to create money through lending. However, physical warehousing is almost completely absent in modern financial systems.⁶ The model could be turned into an exclusively FMC model by assuming either risk-free uncollateralised loans, commodities collateral without physical warehousing, or other and far more common forms of collateral such as real estate. Piazzesi and Schneider (2018) is based on a combination of all three mechanisms for bank balance sheet growth. Linear utility and flexible prices ensure that the dynamic effects of idiosyncratic deposit withdrawal shocks are instantaneous, so that the analysis can concentrate on steady state comparisons. Bank deposits are created through non-banks’ physical saving and the purchase of Lucas trees by banks from non-banks. But households can also obtain liquidity through intraday loans, which are close relatives of the fake receipts of Donaldson et al. (2018). While both purchases of trees and intraday loans can generate rapid changes in the size of bank balance sheets, they are not strictly necessary because of the simultaneous presence of linear consumption utility, which implies that households are able to supply real savings with the same elasticity with which banks are able to supply ledger entries. Chari and Phelan (2014) is based on a combination of the SEC and SAV mechanisms, with bank deposits that are used as a medium of exchange for consumption purposes, but created through a combination of physical asset purchases from and the accumulation of physical savings by households. Because the SEC mechanism plays a very small role empirically, we consider this model class to be very similar to simpler ILF models, which were discussed in Section I. The bank run model of Gertler and Kiyotaki (2015) is also based on a combination of the SEC and SAV mechanisms, with fire sales of securities and valuation losses playing a major role in the evolution of bank balance sheets during runs. But in other respects this model does not fit neatly into our classification. The reason is that these authors divide their economy into shadow banks, who experience runs, and a combination of commercial banks and nonbanks, who run, while the aggregate financing of nonbank borrowers, the main object of interest of our paper, remains constant throughout. This choice is appropriate for the study of financial crises, where securities

⁶Custodial services do not qualify because custodial items are held in trust and not on bank balance sheets.

transactions between different parts of the financial sector have played a critical role even though securities transactions between the financial and nonfinancial sectors and valuation losses have only played a minor role for the aggregate financial sector, as shown in Jakab and Kumhof (2018). Gertler et al. (2015) builds on Gertler and Kiyotaki (2015) but divides the economy into three groups, shadow banks, commercial banks and households. In this model changes in the size of the aggregate financial sector’s balance sheet can be quantified, and are due to changes in direct holdings of securities (capital) by households. Bigio and Weill (2016) is based exclusively on a variant of the SEC mechanism. In this three-period two-state model banks buy high-risk illiquid assets from producers in exchange for issuing low-risk liquid deposits, thereby allowing producers to hire additional workers who will not accept to be paid in high-risk assets. At the final stage however bankers settle their deposit contracts using the physical returns on their assets, so that banks are still intermediaries of physical commodities, and workers still buy the output of producers using physical commodities. This could however be addressed by allowing for a variant of the FMC mechanism in this paper, with workers spending their deposits to buy output from producers, and producers using these deposits to repurchase the illiquid assets. Another difference is that Bigio and Weill (2016) emphasise the asset side of banks, with private portfolio diversification permitting the issuance of low-risk liabilities, while our paper exclusively emphasises the liability side, with loans assumed to be completely risk-free. This permits a significantly more tractable (and infinite horizon) model. In Brunnermeier and Sannikov (2016), unlike Bigio and Weill (2016) and this paper, bank liabilities serve exclusively as a low-risk store of value, while economic exchange is still performed using commodities. Bianchi and Bigio (2014) is based exclusively on the SAV mechanism, with banks intermediating real savings between households and firms. While in this model loans and deposits can experience large jumps, the reason is not an FMC framework but the assumption of an infinitely elastic supply of real savings. While this implies an extreme behaviour of consumption, it facilitates a clearer focus on the main topic of the paper, the interaction between monetary policy and the interbank market.

2.2. Income, Credit and Purchasing Power

In ILF models purchasing power at any given point in time consists of physical resources and is, at the aggregate level, constrained by current income received in the form of commodities. Lending does not relax this constraint, because it transfers commodities from lenders to borrowers, so that any increase in the purchasing power of borrowers is offset by a corresponding reduction in the purchasing power of their lenders. By contrast, in FMC models aggregate purchasing power equals current income plus net new credit, because in this case the debt-financed increase in the purchasing power of borrowers is not offset by a fall in the purchasing power of other agents. The reason is that the new purchasing power is created ex nihilo by an equal increase in the assets and the liabilities of the banking sector. This emphasis on the distinction between income and purchasing power can be traced back to some of the leading economists of the past, including Schumpeter (1934), Keynes (1939) and Kaldor (1989). This tradition continues in the Post-Keynesian literature, which emphasises the ability of commercial banks to create endogenous money that adds to agents’ purchasing power, and the importance of this mechanism for monetary and financial stability, see e.g. Minsky (1977), Moore (1979), Lavoie (2014) and Keen (2014, 2015). Keen argues that endogenous money plays a crucial role in Minsky’s development of the Financial Instability Hypothesis.⁷

⁷Bhattacharya et al. (2015) formalise some of Minsky’s intuition, by modelling endogenous default and endogenous demand for credit and money.

2.3. Contractionary Reductions in Nominal Policy Rates

One of the key conclusions of our paper is that near the ZLB a reduction in the nominal policy interest rate *ceteris paribus* reduces output. The reason is that it reduces banks' lending spreads, credit extension and deposit creation, and that all real activity depends on deposits-based economic exchange.

In the theoretical literature, the paper by Brunnermeier and Koby (2018) makes a related point. It argues that a drop in the policy rate on the one hand increases the net return on high-interest legacy assets while on the other hand squeezing the net interest margin on new loans. Below a "reversal interest rate", which however does not need to be located at zero, the latter effect starts to dominate, so that accommodative monetary policy becomes contractionary. The paper requires a number of assumptions about the pattern of interest semi-elasticities of loan and deposit demands, the exogenous presence of legacy assets on the balance sheet and pre-endowed banking equity in order to determine the reversal interest rate. Our model is simpler and has a different transmission mechanism, the rationing of money creation when deposit interest rates are at their lower bound, which for many countries has indeed been located at or just below zero. Also, Brunnermeier and Koby (2018) focus exclusively on the banking sector and take the rest of the economy, including loan and deposit demands, as given, while our model also describes the general equilibrium interaction between the banking sector and the real economy. Eggertsson et al. (2017) empirically document a collapse in pass-through from policy rates to other rates, especially to deposit rates, once the policy rate turns negative, and provide a New Keynesian model where negative policy rates either have a neutral or a contractionary effect on aggregate demand. The contractionary effect occurs under the additional assumption that an intermediation cost function depends negatively on bank profits. Under this assumption, because paying negative interest rates on reserves reduces bank profits, it increases intermediation costs and thereby lending rates, and the latter reduces aggregate demand. The main difference between this paper and ours is that Eggertsson et al. (2017) is an ILF model, with deposits that are accumulated through physical saving and that themselves do not play a monetary role. The transmission mechanism from lower policy rates to the real economy is therefore different from ours.

The empirical literature documents the effects of long periods at the ZLB on banks' equity and lending in many countries around the world. Landier et al. (2013) focus on the US case, and show that banks retain significant exposure to interest rate risk, that an increase in the Fed funds rate near the ZLB induces banks to increase their quarterly earnings, and that this is in turn associated with stronger bank lending. This is consistent with our theoretical predictions. Heider et al. (2017) focus on the euro area, and show that when the central bank reduces the policy rate to zero or below, banks are reluctant to pass on negative rates to depositors, leading to a reduction of profits and lending, particularly among low risk banks, and to "search for yield" among high risk banks. By contrast, when monetary policy rates are significantly positive this mechanism is of no importance. The latter is consistent with our unconstrained model. Basten and Mariathan (2018) focus on Switzerland, and show that negative interest rates have eroded bank equity. Gerstenberger and Schnabl (2017) focus on Japan, and show that low interest rates have compressed banks' interest margins. Claessens et al. (2017), in a sample of 3385 banks from 47 countries from 2005 to 2013, demonstrate that drops in policy rates adversely affect banks' net interest margins and profitability. Ampudia and Van den Heuvel (2017) show that the decrease in policy rates at the onset of the crisis boosted banks' stock prices, but that the effects reversed during the recent period with low and even negative policy rates.

On the policy front, in 2016 the Bank of England voiced concerns very similar to the ones expressed in this paper, namely that absent additional policy measures further reductions in policy rates might not be fully transmitted to the real economy, because of an erosion in banks' intermediation margin near the ZLB (Bank of England (2016a,b)). The rate cut decision at that time was therefore complemented by the introduction of the Term Funding Scheme (TFS), which provided low-interest funding and additional incentives to banks to help ensure that the rate cut was fully passed through to households and companies, without perverse effects of lower rates on lending.

2.4. Flattening of the Phillips Curve

Since the GFC of 2008, output has in many countries remained far below the pre-recession trend, unemployment has remained stubbornly high and inflation has not fallen by as much as anticipated. In other words, there has been a post-crisis flattening of the Phillips curve. Figure 1 shows the US data. A large literature has studied the reasons for this, but it has not yet converged on a consensus view.⁸

One popular explanation points to the better anchoring of inflation expectations due to central bank gains in credibility. Blanchard et al. (2015) and Blanchard (2016) provide empirical evidence suggesting that the flattening of the Phillips curve started in the 1980's, and that the slope did not decline further after the crisis. The main reason for the flattening of the curve, they argue, is a better anchoring of inflation expectations. This argument is challenged by Kiley (2015), who argues that the anchoring of inflation expectations is insufficient to account for all the inflation inactivity after the crisis. Similarly, Ball and Mazumder (2011) show that the anchoring of inflation expectations can account for the decline of the slope, but only on the strong assumption that expectations stay anchored at 2.5 % for several years when actual inflation was less than 1%.

Another explanation attributes the phenomenon to (typically real) shocks. Leduc and Wilson (2017) use cross-city data in the US to show that there was a decline in the slope of the Phillips curve after the crisis. They argue that this was caused by shocks and that the flattening should be short-lived, with the slope returning to normal once the economy recovers. Laseen and Sanjani (2016) also argue that changes in shocks are a more salient feature of US data than changes in coefficients. Specifically, they argue that exogenous cost-push shocks stopped inflation from falling, so that the claim that the Phillips curve has flattened would be incorrect.

A related set of explanations emphasises longer-term structural changes. Gordon (2013) argues that there has been an increase in the natural rate of unemployment, and that the Phillips curve is alive and well. Christiano et al. (2015), using a DSGE model, attribute the decline in inflation relative to pre-1996 norms to a decline in the growth rate of technology, not to a flat Phillips curve. Another possibility, studied by De Loecker and Eeckhout (2017) and De Loecker et al. (2016), is that competition has declined in the markets for goods and services, leading to a drop in supply and an increase in price markups. Coibion et al. (2017) and Coibion and Gorodnichenko (2015) call for a reconsideration of the formation of inflation expectations to account for the missing disinflation. Some papers also suggest that the reduced form of the Phillips curve would look flat even when the structural form produces a steeper slope. This has been explored by Ball and Mazumder (2011) and by Del Negro et al. (2015).

⁸See International Monetary Fund (2013) for a survey.

The only paper that, to our knowledge, relates the flattening of the Phillips curve to financial frictions is Gilchrist et al. (2017), who show that financially constrained firms increased prices in 2008 while their unconstrained counterparts cut prices. Based on a theoretical model they argue that firms which face a higher external finance premium find it optimal to raise prices even if this implies a sacrifice of future market share, because an improvement in revenue and thus in cash flow reduces the need for external financing. This rationale for price increases is similar to ours while the nature of the financial friction is different. In our model bank credit rationing near the ZLB leads to reduced deposit creation, while in Gilchrist et al. (2017) financial market credit rationing leads to higher external finance premia. Also, the argument of Gilchrist et al. (2017) focuses on the episode of the crisis itself, which was characterised by high credit spreads, whereas our argument is mainly concerned with the post-crisis ZLB period, which was characterised by much lower spreads.

3. Estimation of the Spread Semi-Elasticity of Loan Supply

Our objective in this section is to estimate the semi-elasticity of loan supply with respect to the lending spread, because this is a key input into our model calibration and simulation. We collect US data from the Federal Reserve Bank of St. Louis, Call Reports, Datastream, and the Fed Loan Survey. Table 1 lists the data. The dependent variable is the log of real balances of commercial and industrial (C&I) loans from the US Flow of Funds. The corresponding spread is the spread on C&I loans net of smoothed charge-offs. This is a FISIM interest rate spread calculated using the methodology of Kyle Hood (2013).⁹ The advantage of using a FISIM spread is that it approximates the average interest rate spread on the entirety of C&I loans. To control for endogeneity, we use standard 2SLS and instrument the spread using three candidate instrumental variables (IV) that are correlated with the demand for C&I loans, namely the purchasing manager index (*PMI*), nonfinancial business investment (*INVE*) and the percentage of banks reporting stronger loan demand in the Fed loan survey (*DEMAND*). The latter turns out to be the best IV according to standard criteria, with a four-quarter lag giving the best fit. We introduce three controls that capture shifts of the supply of C&I loans that are independent of the spread, the one-quarter lags of the growth rate of real GDP (Δgdp), banks' liquid to total assets ratio (*liquidity*), and the percentage of banks reporting tightening lending standards to large and medium firms (*supply*).

Table 2 reports estimation results for the instrument $DEMAND_{t-4}$.¹⁰ The interpretation of the coefficient on the lending spread is that a 1 percentage point increase in the spread is associated with, *ceteris paribus*, a 10 percent increase in the level of loans. This will be treated as the baseline value of the short-term semi-elasticity for our model simulations. We do not consider this to be a surprisingly large value, given that a 1 percentage point change in the spread is very large compared to historically observed average spreads for the banking system. Additional considerations apply for the semi-elasticity over the longer run, because banks can over time adapt their business models in order to keep lending despite lower spreads, for example by

⁹FISIM stands for Financial Intermediation Services Indirectly Measured in the System of National Accounts. It is an estimate of the value of the services provided by financial intermediaries, measured by multiplying loans and deposits by FISIM loan and FISIM deposit rate margins, both relative to a common reference rate. We are grateful to Kyle Hood for his support in performing the FISIM calculations.

¹⁰Estimation results for the other instruments are available upon request, and produce estimation results for the elasticity that are as large or larger than the one reported in Table 2.

increasing non-interest income. For the purpose of simulating permanent shocks, we therefore assume that the baseline long-term semi-elasticity equals 5 instead of 10.

The actual evolution of US spreads around the period of the 2008 GFC is shown in Figure 2. We observe that immediately after the crisis all interest rates dropped along with the Fed Funds rate. But the drop in the lending rate was far faster, and followed the Fed Funds rate much more closely. In our model it will follow the Fed Funds rate one for one. The deposit rate on the other hand adjusted much more slowly and was bounded below by zero rather than becoming negative. The consequence of the much faster drop in the lending rate along with the Fed Funds rate was a significant compression in spreads in the two years following the crisis. Spreads did recover later on, due to a combination of deposit rates gradually closing the remaining gap to the ZLB and lending rates starting to exhibit a larger spread relative to the Fed Funds rate. The latter is not part of our model, and accounting for it would make the ZLB less binding over the longer run. However, it does appear to be a clear feature of the data that this process takes time, so that the assumption of a fixed lending spread relative to the policy rate seems appropriate for the analysis of transitory shocks. Furthermore, even by 2016 spreads remained low relative to historical averages, so that some part of the compression in spreads may remain until the economy exits from the ZLB.

4. The Model

4.1. Overview

The model economy consists of four sets of agents, banks, firms, households and government. One period represents one quarter. Upper/lower case symbols represent nominal/real variables. For simplicity we assume that the trend real growth rate and the steady state inflation rate equal zero.

The economy is intertemporally linked through households' holdings of government bonds and physical capital. However, the issuance and retirement of deposit money by banks remains a purely intratemporal process, with new deposits issued by banks at the beginning of each period, and the same deposits being retired, or destroyed, at the end of that period. Figure 3 summarises the intra-period flows of deposits. Each period begins with the realisation of aggregate shocks, the central bank announcement of the policy interest rate, and the government announcement of the labour income tax rate. Immediately after this banks make loans that create deposits for firms. No further deposit creation is permitted inside the period. Banks subsequently provide a costless payment system that the four sets of agents must use to make payments to each other by way of deposit transfers. Banks and the central bank participate in a market for central bank reserves, which banks must use to settle payments imbalances, and with reserve balances paying the policy rate. Banks also have access to the market for government bonds on an intra-period basis, which facilitates interest rate arbitrage between the policy rate and the interest rate on government bonds. Households and government can hold/issue government bonds intertemporally. Firms, once their deposits have been created, face a deposits-in-advance constraint whereby they need to use deposits to make payments ahead of producing commodities. They make payments for wages, rental costs and dividends¹¹ to households and for loan interest to banks, where it is assumed that

¹¹It could alternatively be assumed that monopolistic profits can only be paid out after production has taken place. However, it can be shown that this does not materially change the results, while the exposition under our assumption is considerably simplified.

banks immediately pass those payments through to households as lump-sum dividends.¹² Households, after receiving deposits from firms, are subject to a deposits-in-advance constraint whereby they need to use deposits to make payments ahead of consuming commodities. They make payments for private consumption, private investment and investment adjustment costs to firms. They also need to make payments (labour income taxes, purchases of net new government bonds) to government by way of deposits, and government, once it has received these deposits, needs to use them to make payments to firms (government consumption) and households (interest on government debt).¹³ Once households and government have paid firms for their newly produced commodities, all circulating deposits have returned to firms and firms repay their loans in full. Banks' balance sheets vanish for an instant before the beginning of the next period.

In this economy all money is endogenous deposit money, with no exogenous endowment of commodity money or of government fiat money. The price level is nevertheless determinate, through what Calvo (2012, 2016) refers to as the price theory of money, whose origin he traces back to Keynes' General Theory. In this theory money derives its liquidity and positive purchasing power from the existence of sticky commodity prices, which provide an output backing to money. Specifically, when banks create new nominal deposit money balances this translates to an increase in real money balances because sticky prices guarantee that the purchasing power over commodities of the new money cannot be immediately inflated away by changes in the price level.

4.2. Banks

There is a continuum of banks of measure 1, with an individual bank indexed by j . Bank loans $L_t(j)$ that charge an interest rate i_t^l create deposit money $D_t^f(j)$ that pays an interest rate i_t^d , subject to an increasing and convex marginal cost of making loans $C(L_t(j))$.¹⁴ Deposit creation is performed exclusively for firms and exclusively at the beginning of each period. This helps to keep the model tractable but can be generalised.

Banks are ex-ante identical, and therefore make identical loans to firms, both in terms of quantity and pricing. Their customers spread their deposit balances evenly across banks, so that any subsequent payments between non-banks do not lead to individual banks being short or long in deposits, and therefore in central bank reserves. We make the simplifying assumption that there is no difference between the interest rates on central bank reserve deposits and reserve loans, so that it becomes unnecessary to explicitly model the market for reserves. The interest rate on reserves, and therefore the interest rate on interbank loans (of reserves), will be referred to as the policy rate, and denoted by i_t . With the foregoing assumptions, all banks have identical balance sheets at all times, with loans equalling deposits and zero positions in the market for reserves. If an individual bank deviated from this equilibrium, by making more or fewer loans than other banks, this would have its balance sheet counterpart in a short or long position in the interbank market. This is however ruled out by arbitrage.

Specifically, competition between banks ensures that no individual bank has an incentive to deviate, by eliminating the possibility of profiting from making more or fewer loans. This incentive is eliminated when the interest rate on loans equals the marginal cost of funding

¹²These dividends represent a conversion of bank equity (earned through loan interest) into bank deposits that are then transferred to households.

¹³In reality government treasuries receive and make payments into and from reserve accounts at the central bank, upon clearing of the underlying payment instrument. We abstract from this without loss of generality.

¹⁴For another use of an exogenous intermediation cost function see Eggertsson et al. (2017).

additional loans through the interbank market, $i_t^\ell = i_t$. In the data actual lending rates are generally higher than the policy rate, and our model could be generalised to account for this by adding risk-based markups, but at considerable costs in model complexity. This would however have the benefit of allowing the model to account for situations where policy rates have reached zero while lending rates remain above zero.

The interest rate on government bonds also has to equal the policy rate by arbitrage. Banks, together with the central bank/government, have intra-period access to both the market for reserves and the government bond market. If the two interest rates did not coincide banks would be able to make profits by taking long positions in one market and short positions in the other. Absent arbitrage opportunities, there is no demand from banks for a nonzero net supply of reserves, and reserves have no implications for the government budget.

An important question concerns the recipient of the interest paid on deposits. We observe that money circulates inside each period, so that any deposit is held by multiple agents before it is destroyed at the end of the period. The assignment of the recipient of deposit interest is therefore necessarily arbitrary. For simplicity and ease of interpretation, we assume that all deposit interest is received by firms. This ensures that the spread enters in a single location in the model, namely in the Phillips curve. It represents the opportunity cost of having banks create money for firms, with the benefit being the relaxation of firms' deposits-in-advance constraint.

There is free entry into banking. Bank profits $\Pi_t^b(j)$ consist of two elements, the interest rate spread between loans and deposits $(i_t - i_t^d) L_t(j)$ and the cost of making loans $C(L_t(j))$. The profit maximisation problem is

$$\underset{L_t(j)}{\text{Max}} \Pi_t^b(j) = (i_t - i_t^d) L_t(j) - C(L_t(j)) . \quad (1)$$

We assume that $C(L_t(j))$ represents a lump-sum transfer to households rather than a resource cost. Because banks also transfer their profits to households, total receipts of households from bank j equal $(i_t - i_t^d) L_t(j)$. We assume that $C(L_t(j))$ is increasing at an increasing rate in the quantity of loans:

$$C(L_t(j)) = \frac{\kappa}{1 + \frac{1}{\xi}} P_t \ell_t^{tgt} \left(\frac{L_t(j)}{P_t \ell_t^{tgt}} \right)^{1 + \frac{1}{\xi}} . \quad (2)$$

The target loan volume ℓ_t^{tgt} is a first-order autoregressive process with a steady state value of $\bar{\ell}^{tgt}$. Shocks to this process change the loan supply at a given interest rate spread. We will refer to this as the autonomous loan supply, and its economic interpretation is as an exogenous shock to banks' willingness to extend loans. In equilibrium all banks face identical problems and make identical choices, so that the index j can be dropped in the loan optimality condition, which is given by

$$\ell_t = \ell_t^{tgt} \left(\frac{i_t - i_t^d}{\kappa} \right)^\xi , \quad (3)$$

with $i_t^d = 1$ at the ZLB. This shows that away from the ZLB credit supply responds highly elastically to credit demand, as i_t^d can adjust so that the bank can accommodate credit demand while making zero profits at the margin, and that at the ZLB credit supply does not respond at all to credit demand, as ℓ_t must adjust so that the bank can continue to make zero profits at the margin. The parameter ξ plays a critical role for the quantity of loans at the ZLB, while it mainly determines the evolution of deposit interest rates away from the ZLB. The equation (3) can be used to compute the spread semi-elasticity of the supply of loans with respect to the spread,

$d \ln (\bar{\ell}_t / \bar{\ell}) / d \hat{i}_t$, where $\hat{i}_t = (i_t - i_t^d) * 400$, as a function of ξ . Following the empirical results of Section 3 we set this elasticity equal to 10, meaning that loan supply increases by 10 percent for a 1 percentage point increase in the spread.

4.3. Firms

There is a continuum of firms of measure 1, with an individual firm indexed by j . Each firm produces output $y_t(j)$ at price $P_t(j)$, subject to monopolistic competition and stickiness in inflation. Aggregate output y_t is a Dixit-Stiglitz aggregate over varieties $y_t(j)$, with elasticity of substitution θ , and the corresponding aggregate price level and inflation rate are P_t and π_t . Real inflation adjustment costs are given by

$$G_{P,t}(j) = \frac{\phi_p}{2} y_t \left(\frac{\frac{P_t(j)}{P_{t-1}(j)}}{\pi_{t-1}} - 1 \right)^2, \quad (4)$$

where ϕ_p calibrates the degree of inflation stickiness. Each firm hires labour $h_t(j)$ and capital $K_t(j)$ at competitive nominal/real prices W_t/w_t and R_t^k/r_t^k . Aggregate labour h_t and capital K_t are integrals over $h_t(j)$ and $K_t(j)$, respectively. The firm obtains loans to satisfy a deposits-in-advance constraint, and pays a gross nominal interest rate of i_t on the loans while earning a gross nominal interest rate of i_t^d on the corresponding deposits. The nominal profit of firm j is therefore given by

$$\Pi_t^F(j) = P_t(j)y_t(j) - W_t h_t(j) - R_t^k K_t(j) - L_t(j)(i_t - i_t^d) - P_t G_{P,t}(j). \quad (5)$$

The deposits-in-advance constraint of firm j states that it needs to use its deposits $D_t^f(j)$ to pay net interest to its bank, wages to its workers, rental costs to its providers of capital and dividends to its shareholders, all ahead of production. Using the equality $D_t^f(j) = L_t(j)$ we therefore have the constraint

$$L_t(j) \geq L_t(j)(i_t - i_t^d) + W_t h_t(j) + R_t^k K_t(j) + \Pi_t^F(j). \quad (6)$$

The left-hand side of this constraint represents the total liquidity generated for the firm by the bank. The right-hand side represents the payments made with these deposits. We adopt the notation $D_t^{hb}(j) = L_t(j)(i_t - i_t^d)$ (deposits to cover net interest payments, which are received by banks from firms and then by households from banks), $D_t^{hf}(j) = W_t h_t(j) + R_t^k K_t(j)$ (deposits to cover wage and user cost payments, which are received by households from firms) and $D_t^{hm}(j) = \Pi_t^F(j)$ (deposits to cover firm payouts of monopolistic profits, which are received by households from firms). Inflation adjustment costs $P_t G_{P,t}(j)$ are paid by firms to each other, and therefore do not change the bank deposits of the aggregate firm sector. The deposits-in-advance constraint must be binding in equilibrium, because the opportunity cost to firms of having banks create idle deposit balances for them, the spread $i_t - i_t^d$, is positive by the bank's optimisation problem. As to whether current income or net new credit finances spending, the key observation is that prior to starting production firms' current income equals zero, and it is *only* the extension of new credit that allows the production cycle to start.

Combining (5) and (6), we obtain the final form of the deposits-in-advance constraint:

$$L_t(j) \geq P_t(j)y_t(j) - P_t G_{P,t}(j). \quad (7)$$

The firm's technology is standard, with the supply of output $y_t^s(j)$ given by

$$y_t^s(j) = S_t^a h_t(j)^{1-\alpha} K_t(j)^\alpha, \quad (8)$$

where α calibrates the capital share in output and S_t^a is a first-order autoregressive process for total factor productivity. Standard optimisation with imperfectly substitutable output varieties yields the demand for output $y_t^d(j)$,

$$y_t^d(j) = (P_t(j))^{-\theta} (P_t)^\theta y_t ,$$

where in equilibrium $y_t^d(j) = y_t^s(j)$. The optimisation problem of firms is

$$\begin{aligned} \underset{\{P_t(j), h_t(j), K_t(j), L_t(j)\}_{t=0}^{\infty}}{\text{Max}} \quad & E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t^h \left[(P_t(j))^{1-\theta} (P_t)^\theta y_t - W_t h_t(j) - R_t^k K_t(j) - L_t(j)(i_t - i_t^d) \right] \quad (9) \\ & - \frac{\phi_P}{2} P_t y_t \left(\frac{P_t(j)}{\pi_{t-1}} - 1 \right)^2 - MC_t \left((P_t(j))^{-\theta} (P_t)^\theta y_t - S_t^a h_t(j)^{1-\alpha} K_t(j)^\alpha \right) \\ & + \eta_t^f \left(L_t(j) - (P_t(j))^{1-\theta} (P_t)^\theta y_t + \frac{\phi_P}{2} P_t y_t \left(\frac{P_t(j)}{\pi_{t-1}} - 1 \right)^2 \right) \\ & - \eta_t^b \left(L_t(j) - P_t \ell_t^{tgt} \left(\frac{i_t - i_t^d}{\kappa} \right)^\xi \right) \end{aligned} ,$$

where β is the household intertemporal discount factor and Λ_t^h is the multiplier of the household's nominal budget constraint. The corresponding multiplier of the real budget constraint is λ_t^h . The firm maximises the present discounted value of its profits subject to three constraints. First, aggregate supply must equal aggregate demand, with a multiplier on this constraint of MC_t , which denotes nominal marginal cost. Second, the deposits-in-advance constraint (7) must hold, with a multiplier of η_t^f . Third, banks' participation constraint (3), or credit rationing constraint¹⁵, must hold, with a multiplier of η_t^b . This third constraint behaves differently depending on whether the economy is at the ZLB. Namely, away from the ZLB the interest rate i_t^d is free to vary to achieve the spread that is necessary for the bank to elastically accommodate loan demand. Therefore, there is no credit rationing and $\eta_t^b = 0$. At the ZLB, we have $i_t^d = 1$ so that in general $\eta_t^b > 0$. In this case, changes in η_t^b depend on relative changes in loan supply and loan demand.

The firm's optimality conditions for capital and labour are standard, and we do not show them here to conserve space. But the Phillips curve is now affected by credit rationing

$$\frac{\mu mc_t}{(1 - \eta_t^f)} - 1 = \phi_p (\mu - 1) \left(\frac{\pi_t}{\pi_{t-1}} - 1 \right) \frac{\pi_t}{\pi_{t-1}} - \beta \frac{\lambda_{t+1}^h}{\lambda_t^h} \frac{y_{t+1}}{y_t} \frac{(1 - \eta_{t+1}^f)}{(1 - \eta_t^f)} \phi_p (\mu - 1) \left(\frac{\pi_{t+1}}{\pi_t} - 1 \right) \frac{\pi_{t+1}}{\pi_t} = 0 , \quad (10)$$

where mc_t is real marginal cost and $\mu = \theta / (\theta - 1)$. The optimality condition for loans is

$$i_t - i_t^d = \eta_t^f - \eta_t^b . \quad (11)$$

Away from the ZLB this simplifies to $1 - \eta_t^f = 1 - i_t + i_t^d$, so that the Phillips curve is directly affected only by the lending spread, with no role for quantity rationing of credit. On the other hand, at the ZLB we have $1 - \eta_t^f = 2 - i_t - \eta_t^b$, in other words the multiplier on the credit rationing constraint directly enters the Phillips curve.

¹⁵In our terminology credit rationing refers to quantity rationing rather than price rationing of credit.

4.4. Households

There is a continuum of households of measure 1, with an individual household indexed by j . Households maximise their lifetime utility over consumption $c_t(j)$ and hours worked $h_t(j)$, subject to consumption demand shocks S_t^c that follow a first-order autoregressive process, and with intertemporal elasticity of substitution ϵ , external habit persistence v , a weight on labour disutility of χ , and a labour supply elasticity of 1:

$$\underset{\{c_t(j), h_t(j), I_t(j), k_t(j), B_t(j)\}_{t=0}^{\infty}}{\text{Max}} E_0 \sum_{t=0}^{\infty} \beta^t [S_t^c (1-v)^{\frac{1}{\epsilon}} \frac{(c_t(j) - v c_{t-1})^{1-\frac{1}{\epsilon}}}{1 - \frac{1}{\epsilon}} - \frac{\chi}{2} h_t(j)^2] . \quad (12)$$

Households accumulate nominal government bonds $B_t(j)$ and physical capital $k_t(j)$, with nominal net returns $i_t - 1$ and R_t^k . Net interest on government bonds held between periods t and $t + 1$ is received in period t , with only the principal settled in period $t + 1$. This treatment of interest is equivalent to the treatment of private loan (and deposit) interest. The difference is that loans are always repaid in full before being renewed while government debt is not.

All household income and expenditure payments are made in the form of bank deposits. Households receive factor incomes $W_t h_t(j)$ and $R_t^k k_{t-1}(j)$ and lump-sum dividend incomes $D_t^{hm}(j)$ and $D_t^{hb}(j)$. Their first deposits-in-advance constraint is that these incomes must be sufficient to cover gross payments to the government:

$$W_t h_t(j) + R_t^k k_{t-1}(j) + D_t^{hm}(j) + D_t^{hb}(j) \geq B_t(j) - B_{t-1}(j) + W_t h_t(j) \tau_{L,t} . \quad (13)$$

In our simulations this constraint is never binding. For future reference, we denote the net aggregate deposits collected by the government from households by $D_t^{gh} = B_t - B_{t-1} + W_t h_t \tau_{L,t}$. Households's second deposits-in-advance constraint is that their factor and dividend incomes minus net payments (net of interest received) to the government must be sufficient to cover payments for commodities purchases to firms, which include consumption $P_t c_t(j)$, investment $P_t I_t(j)$ and investment adjustment costs $P_t G_{I,t}(j)$, where real investment adjustment costs equal

$$G_{I,t}(j) = \frac{\phi_I}{2} I_t \left(\frac{I_t(j)}{I_{t-1}(j)} - 1 \right)^2 , \quad (14)$$

and where ϕ_I calibrates the degree of investment inertia. We therefore have

$$W_t h_t(j) + R_t^k k_{t-1}(j) + D_t^{hm}(j) + D_t^{hb}(j) + B_t(j)(i_t - 1) - (B_t(j) - B_{t-1}(j)) - W_t h_t(j) \tau_{L,t} \geq \quad (15)$$

$$P_t c_t(j) + P_t I_t(j) + P_t G_{I,t}(j) .$$

This deposits-in-advance constraint is binding in equilibrium as long as the opportunity cost to households of investing in idle and (for households) zero interest deposit balances, the net interest rate on government bonds $i_t - 1$, is kept positive at all times. This will be true in all our simulations. If it was not, it would result in the complete cessation of bank lending and therefore of real activity. In the case of households spending is financed entirely through current income because they only have access to the payment system. Of course in a richer model households could also have access to bank credit. Finally, the accumulation equation for physical capital is given by the law of motion

$$k_t(j) = (1 - \delta) k_{t-1}(j) + I_t(j) , \quad (16)$$

where δ is the depreciation rate of capital. The household problem as set up here is standard for New Keynesian models. All optimality conditions are therefore also standard, and we do not show them here to conserve space.

4.5. Government

The government's deposits-in-advance constraint is given by

$$D_t^{gh} \geq B_t (i_t - 1) + P_t g_t . \quad (17)$$

This constraint must be binding in equilibrium because the cost to government of borrowing to acquire idle and (for government) zero interest deposit balances, the net interest rate $i_t - 1$, is positive at all times by the arguments of subsection 4.4. Government spending is financed entirely through current income, including household income transferred to government in exchange for new government bonds. The labour tax rate is determined by the fiscal rule

$$\tau_{L,t} - \bar{\tau}_L = f_b \left(\frac{b_t}{4y_t} - \frac{\bar{b}}{4\bar{y}} \right) , \quad (18)$$

where f_b is the feedback coefficient on the debt-to-GDP ratio. The monetary policy rule is given by

$$i_t = ((2 - \beta) \pi_t) \left(\frac{\pi_t}{\bar{\pi}} \right)^{m_\pi} \left(\frac{\ell_t}{\bar{\ell}} \right)^{m_\ell} S_t^{int} , \quad (19)$$

where m_π is the inflation gap feedback coefficient, m_ℓ is the loans gap feedback coefficient and S_t^{int} is a first-order autoregressive process for monetary policy shocks. The target real interest rate $2 - \beta$ is consistent with the economy's steady state real interest rate, and the target for gross inflation is $\bar{\pi}$. The Taylor principle corresponds to $m_\pi > 0$.

4.6. Market Clearing and GDP

The goods market clearing condition is

$$y_t = c_t + I_t + g_t + G_{p,t} + G_{I,t} . \quad (20)$$

The market clearing condition for physical capital is

$$K_t = k_{t-1} . \quad (21)$$

And finally, GDP is defined as

$$gdp_t = c_t + I_t + g_t . \quad (22)$$

4.7. Calibration

Table 3 presents the details of our model calibration. It distinguishes between calibrated parameter values in the ZLB-constrained economy (fourth column) and in the unconstrained economy (fifth column). The discount factor β is set to fix the steady state real policy interest rate at 3% per annum in both models. The nominal and real rates are equal in steady state because the central bank's net inflation target equals 0% per annum. Keeping the steady state policy rate equal across models has the advantage of implying very similar steady state real variables as we move from high-interest unconstrained to low-interest ZLB-constrained economies.¹⁶ Instead of differences in the steady state policy rate, distinctions between unconstrained and

¹⁶Otherwise there would for example be very large differences in steady state capital stocks.

ZLB-constrained models are assumed to be due to differences in the steady state deposit interest rate. We specify three models that differ by the value taken by that rate, an unconstrained model with a rate of 1% per annum, a ZLB-constrained model with a 0% rate, and a hypothetical unconstrained model with a -1% rate. The first and third models are used to calibrate two sets of the parameters of the loan supply cost function (2), $\bar{\ell}^{tgt}$, κ and ξ . For the third model these three parameters are then applied to the ZLB-constrained model. The idea is that a “fundamental” loan supply cost function can be identified from the unconstrained model under the assumption that deposit rates can become negative, and that the ZLB does not affect this function but instead forces the economy’s steady state, and especially banks’ lending volume, to adjust to the constraint given this function. In both unconstrained economies the elasticity parameters ξ are set to fix the steady state spread semi-elasticity of loan supply at 10 in the baseline, and at 5 and 1 in two alternatives. The parameters κ are set to fix the steady state real deposit rates at 1% and -1% per annum, respectively, while the steady state levels of loans $\bar{\ell}^{tgt}$ are determined by loan demand at that interest rate. The implied interest semi-elasticities of the ZLB-constrained model are slightly higher than in the corresponding unconstrained model, at 11.9, 6.3 and 1.3, respectively. This small difference has no significant effects on our simulation results.

The remainder of the calibration applies equally to both models. For preferences, households’ intertemporal elasticity of substitution equals $\epsilon = 0.5$, the habit persistence parameter equals $v = 0.75$, and the weight χ on hours in the utility function is set to normalise steady state labour supply to 1. For technologies, the production function parameter α is set to fix the steady state ratio of labour income to GDP at 60%, and the depreciation rate δ is set to fix the investment-to-GDP ratio at 20%. Both are in line with recent US data. We calibrate the steady state government spending to GDP ratio at 18%, and the steady state level of the labour income tax rate is set to be consistent with a steady state government debt to GDP ratio of 100%. The calibration of the investment adjustment cost parameter $\phi_I = 2.5$ follows Christiano et al. (2005). The steady state gross markup, in line with much of the New Keynesian literature, is set to $\mu = 1.1$, and the degree of price stickiness to $\phi_p = 200$. Together these values imply a contract duration of 5 quarters in an equivalent Calvo (1983) model. In the fiscal policy rule the debt feedback coefficient is set to $f_b = 0.1$. In the monetary policy rule the baseline inflation gap and loans gap feedback coefficients are fixed at $m_\pi = 3.0$ and $m_\ell = 0$. We will perform sensitivity analysis for both of these coefficients. The persistence of first-order autoregressive shocks in our simulations is $\rho_c = 0.7$ for consumption (habit persistence imparts additional persistence to this shock), $\rho_a = 0.95$ for technology, $\rho_\ell = 0.9$ for loan supply and $\rho_{int} = 0.9$ for shocks to the monetary policy rule.

5. Model Simulations

In this section we discuss impulse responses that first (in the top half of each figure) illustrate the behaviour of the ZLB-constrained economy as a function of the spread semi-elasticity of loan supply, and that then (in the bottom half of each figure) compare the behaviour of the ZLB-constrained economy to an otherwise identical unconstrained economy. In each case the black solid, blue dashed and red dotted lines show simulations for the ZLB-constrained economy with spread semi-elasticities of 10/5/1, while the green dashed line shows the simulation for the unconstrained economy with a spread semi-elasticity of 10. The first subsection illustrates why in a ZLB-constrained economy systematic reductions in the nominal policy rate in response to lower inflation are contractionary and why the Phillips curve becomes much flatter than in the

unconstrained economy. The second subsection illustrates how in a ZLB-constrained economy a policy of deliberately increasing inflation and therefore the nominal policy rate, either through exogenous shocks to the policy reaction function or through a policy reaction function with an endogenous response to the loans gap, can have strong expansionary effects by stimulating bank lending. In the ZLB-constrained economy we limit ourselves to simulating shocks that are small enough for the economy to not be close to transitioning to the unconstrained economy and vice versa.

5.1. Reductions in the Policy Rate Are Contractionary Near the ZLB

This subsection studies three shocks that have a disinflationary effect, and that therefore trigger a reduction in the nominal policy rate through the systematic component of the monetary policy rule. While this response has well-known output-stabilising effects in an unconstrained economy, it unambiguously reduces output in a ZLB-constrained economy unless the spread semi-elasticity of loan supply is extremely low. The reason is that even for moderately low semi-elasticities the effect of lower policy rates on the quantity of credit and money dominates other effects, including the effects of changes in the real interest rate.

5.1.1. Consumption Demand Shock

The top half of Figure 4 shows the simulated effects of a shock to consumption preferences S_t^c whereby consumption in the ZLB-constrained economy drops by around 1.4% on impact. The shock leads to a reduction in the demand for capital and labour that triggers a reduction in wages and user costs and therefore, *ceteris paribus*, in inflation. However, the overall impact on inflation also depends on the credit rationing constraint, which in turn depends on the relative effect of the shock on the demand and supply of credit. By the deposits-in-advance constraint the drop in aggregate demand reduces the demand for credit. But by the monetary policy rule the reduction in inflation leads to a drop in the policy rate that reduces the lending spread and thereby the supply of credit. When credit supply is highly elastic with respect to the lending spread, a decrease in the policy rate leads to an especially strong decrease in the supply of credit. The drop in credit supply is therefore larger than the drop in credit demand, thereby increasing the credit rationing multiplier and, *ceteris paribus*, marginal cost. This partly offsets the drop in wages and user costs and thus makes inflation fall by less under more elastic credit supply, while output, which is directly constrained by the quantity of credit and money, falls by more. On the other hand, when credit supply is less elastic, the reduction in credit supply is smaller while the increase in credit demand is larger. The latter occurs because the credit rationing component of marginal cost increases less strongly so that the inflation rate drops by more, which in turn leads to a stronger drop in the real policy rate and thus a *ceteris paribus* stimulus to aggregate demand and thereby to the demand for credit. It can be shown that if the spread semi-elasticity of loan supply becomes even smaller than in Figure 4, specifically as it drops below 0.5, the credit rationing multiplier drops on impact rather than rising.

The reason why interest rates and therefore lending spreads drop in response to the shock is that we have assumed a conventional Taylor rule with a positive feedback coefficient on the inflation gap. What Figure 4 shows is that at the ZLB this type of systematic policy is contractionary *ceteris paribus* due to the credit channel. In subsection 5.2.2 we will discuss how a different monetary policy rule can modify this outcome.

The bottom half of Figure 4 shows the same shock as the top half. It compares the ZLB-constrained and unconstrained economies, in each case with a spread semi-elasticity of 10. Because the shock to consumption preferences is identical, the consumption responses are similar, but otherwise the results are strikingly different. For the unconstrained economy the effect of the credit component $1/(1 - i_t + i_t^d)$ on marginal cost is negligible and does not offset the drop in wages and user costs. As a result, the drop in inflation is much larger despite a much smaller drop in wages and user costs, and leads to a large drop in the nominal and real policy rate. But this is accompanied by a similar drop in the deposit rate, with the result that the effect on the lending spread is smaller than in the ZLB-constrained economy, and only reflects the lower marginal cost of lending after the drop in consumption demand and therefore in credit demand. The absence of credit rationing leaves banks free to supply the quantity of credit demanded by firms, while lower real policy rates stimulate aggregate demand and thereby the demand for credit. Both limit the contractionary output effects of the shock, with a smaller drop in consumption and a strong increase rather than a decrease in investment. For the ZLB-constrained economy, credit rationing has a large negative effect on output. As for inflation, the larger drop in output leads to a much larger drop in wages and user costs, but this is accompanied by an offsetting increase in the credit rationing component of marginal cost, with the net result of a much more subdued inflation response. In other words, the Phillips curve of the ZLB-constrained economy is much flatter than that of the unconstrained economy when we use our estimated value of the spread semi-elasticity. As discussed above, this changes as the elasticity drops towards zero. It can be shown that at an elasticity of around 0.5 the magnitudes of the inflation and output responses become similar to those of the unconstrained economy, but that elasticity is far outside the range suggested by our data.

5.1.2. Technology Shock

The top half of Figure 5 shows the simulated effects of a persistent shock to S_t^a whereby total factor productivity increases by 1.0% on impact. In the ZLB-constrained economy this otherwise expansionary shock nevertheless leads to an output drop of almost 0.6% after 6 quarters. The reason is that an expansionary technology shock *ceteris paribus* reduces inflation and therefore, due to the monetary policy rule, the policy rate, the lending spread and credit, which in turn dampens the effect on inflation. With less elastic credit supply we again observe less credit rationing, more stable output and a larger drop in inflation.

The bottom half of Figure 5 shows that in the unconstrained economy the favourable technology shock is indeed expansionary. The dominant effect on inflation is the drop in wages and user costs, with a negligible contribution of the credit component $1/(1 - i_t + i_t^d)$ on marginal cost. While this leads to a significant reduction in the nominal policy rate, the deposit rate drops by even more, thereby allowing the lending spread to rise and giving banks an incentive to supply the additional credit and money that is needed by an economy that tries to realise the potential of improved technology.

5.1.3. Loan Supply Shock

The top half of Figure 6 shows the simulated effects, in the ZLB-constrained economy, of a persistent shock to ℓ_t^{tgt} whereby the autonomous loan supply increases by just under 2% on impact. The shock relaxes the credit rationing constraint and thereby reduces marginal cost and inflation, while increasing output by around 0.2% after one year in the baseline, and by 0.4% and

0.9% in the scenarios with lower spread semi-elasticity of loan supply. Because the primary effect of the shock is to increase credit, it remains expansionary despite the fact that, due to the monetary policy rule, lower inflation triggers a drop in the policy rate and in the lending spread, which *ceteris paribus* reduces credit. With less elastic credit supply we observe a stronger relaxation of the credit rationing constraint because the drop in the lending spread only leads to a small reduction in credit. As a result inflation drops by more while output increases more strongly.

The bottom half of Figure 6 shows that in the unconstrained economy an increase in the deposit interest rate offsets most of the effects of the shock on credit, so that both the drop in inflation and the increase in output are much smaller than in the ZLB-constrained economy.

5.2. Inflationary Policies Are Highly Expansionary Near the ZLB

This subsection studies three policies that have an inflationary effect, and that therefore trigger an increase in the nominal policy rate, the lending spread, credit, money and output. A short-term expansionary effect of temporary inflationary policies is of course not a surprising result. The point is rather that in a ZLB-constrained economy such policies have a far greater expansionary effect because they reduce the severity of credit rationing. Furthermore, in a ZLB-constrained economy permanent inflationary policies, which have virtually no real effect in an unconstrained economy, have a very strong and permanent effect on output.

5.2.1. Temporary Monetary Policy Shock

The top half of Figure 7 shows a shock to the monetary policy rule S_t^{int} that would, in the absence of an interest rate response to inflation, lead to a 2.4% per annum reduction in the policy rate. In the ZLB-constrained baseline economy this shock leads to an increase in output by around 1% after one year. The reason is that the lower real interest rate stimulates strong increases in consumption and investment demand, and that credit and money accommodate this expansion because the immediate increase in inflation leads to an increase in the nominal policy rate and the lending spread.¹⁷ With less elastic credit supply we observe a weaker relaxation of the credit rationing constraint. As a result inflation increases by more while output increases less strongly.

The bottom half of Figure 7 shows that in the unconstrained economy the stimulus effect of the shock is not amplified by a credit channel, as the nominal deposit rate follows the policy rate to keep the lending spread nearly constant. The expansionary effects of the shock are now solely driven by a short-lived reduction in the real interest rate.

5.2.2. Changes to the Monetary Policy Rule

The simulations in Figures 4-7 emphasise that at the ZLB, while systematic reductions in the nominal policy rate in response to disinflationary shocks are contractionary, policies that generate inflation and a higher nominal policy rate independently of shocks are expansionary. This raises two questions: First, would a weaker systematic response to inflation mitigate the contractionary effects? Second, could a systematic response to other gap variables stabilise output more effectively? Figure 8 shows that the answer to the first question is no while the answer to the second question is yes.

¹⁷The credit rationing multiplier increases in the impact period because the lending spread and therefore credit supply does not rise as fast as consumption and investment and therefore credit demand.

The top half of Figure 8 studies the same shock to consumption demand as in Figure 4, in the ZLB-constrained economy and with a spread semi-elasticity of loan supply of 10. It varies the inflation gap feedback coefficient m_π from 3 to 1.5 to 0.1. This figure shows that with a weaker inflation response the inflation rate drops by slightly more following the shock while the policy rate exhibits virtually no change. The main change is therefore a slightly smaller drop in the real policy rate, while there is virtually no change in the lending spread and credit. The slightly higher real policy rate in turn implies a slightly larger initial decline in investment and output. This clearly does not support a policy of responding less strongly to inflation.

The bottom half of Figure 8 again studies the same shock, but in this case varies the loans gap feedback coefficient m_ℓ from 0 to 2 to 8. With a positive loans gap coefficient m_ℓ , when banks reduce credit due to insufficient lending spreads, this *ceteris paribus* triggers a systematic (rules-based) reduction in the policy rate, thereby generating the same immediate inflationary response that we observed for the non-systematic monetary policy shock of Figure 7. Therefore, the actual policy rate, and therefore lending spreads and credit, increase relative to the case of $m_\ell = 0$. This significantly reduces credit rationing while permitting a larger drop in the real policy rate due to higher inflation. The combination of both effects implies a much shallower contraction, specifically a smaller drop in consumption and an increase rather than a drop in investment. Near the ZLB a monetary policy response to the loans gap therefore becomes a powerful countercyclical tool.

Figure 9 studies the determinacy properties of the monetary policy rule (19) as a function of the feedback coefficients m_π and m_ℓ . We begin with the bottom plot for the unconstrained economy, which shows that the Taylor principle holds at $m_\ell = 0$, but that a slightly weaker inflation response becomes possible as m_ℓ grows. The reason is that an interest rate response to the loans gap can substitute for a response to inflation, because a drop in loans, by (3), implies a drop in the credit rationing component of marginal cost $1/(1 - i_t + i_t^d)$. But this effect is weak given the small role played by the credit rationing component in the determination of inflation. For the same reason, with a strong inflation feedback at $m_\pi = 3$ any loans gap feedback is compatible with determinacy. The picture for the ZLB-constrained economy in the top half of Figure 9 is very different. Here the loans gap becomes much more important, with $m_\ell \geq 0$ required except at extremely high inflation gap coefficients. More importantly, as long as $m_\ell \geq 0$ the inflation gap coefficient can become negative, with only a very weak requirement on the overall response to inflation of $1 + m_\pi > 0$. In other words, an interest rate response to the loans gap can substitute for a response to inflation, because the credit rationing component of marginal cost plays a much bigger role in the determination of inflation.

5.2.3. Permanent Increase in the Inflation Target

Because a ZLB-constrained economy operates permanently below capacity, specifically below the capacity that it could attain in the absence of credit rationing, additional credit and money can increase the economy's output. But this immediately raises the question of why such a policy would be pursued by means of temporary shocks as in Figure 7, or of temporary responses to temporary shocks as in Figure 8, rather than by policies that permanently improve banks' lending margins. This is the subject of our final simulation in Figure 10, which studies the effects of permanently increasing the nominal policy rate for a given equilibrium real interest rate, through a permanent increase in the inflation target in the monetary policy rule. In Figure 10 we assume that the policymaker increases this target, immediately and permanently, by 0.25 percentage

points. The figure shows the effects of this policy under lending spread semi-elasticities of 5 and 1. As we argued above, for permanent policy changes one should take into account that the longer-run semi-elasticity would likely not be as high as the short-run semi-elasticity, because in the long run banks can at least partly adapt their business models to lower lending spreads.

As shown in the top half of Figure 10, the effect of this policy is to immediately stimulate an increase in inflation that is initially even larger than 0.25 percentage points. This leads to increases in the nominal policy rate and the lending spread, and therefore supports an increase in credit that depends on the spread semi-elasticity, with the increase reaching more than 4% on impact and 1.5% in the long run for the case of a semi-elasticity of 5, and under 0.5% for the semi-elasticity of 1. This in turn permits similar long-run increases in output, for what is a very modest increase in inflation.

6. Conclusions

We have studied an infinite-horizon New Keynesian model with endogenous creation of bank deposits through bank loans, subject to an increasing marginal cost of lending. Banks do not intermediate commodity deposits between savers and borrowers, instead they offer a payment system that intermediates ledger-entry deposits between different spenders. This monetary exchange never settles into permanent saver-borrower relationships, instead deposits created at the beginning of each period are extinguished at the end of the period, when the original deposit has circulated back to the original borrower-depositor through a chain of payments. Banks are essential for economic activity, not only because the payment system is essential but also because additional deposit creation increases non-banks' aggregate purchasing power beyond their income alone. In other words, non-banks as a whole do not face a budget constraint whereby their expenditure has to equal their income, instead they face a deposits-in-advance constraint whereby their expenditure has to equal their income plus net new deposit creation, and where additional deposits can mobilise additional resources and thereby create additional income. This implies that any friction that prevents banks from elastically supplying deposits can have important real economic consequences. The friction that we study in this paper is the zero lower bound (ZLB) on deposit interest rates, in an economy where lending interest rates move towards zero with the policy rate and therefore compress lending spreads. After calibrating our model with the sizeable semi-elasticity of loan supply with respect to the lending spread that we estimated from US data, and even calibrating it with much more moderate semi-elasticities, we find that, once deposit rates have reached the ZLB, any further drop in the policy rate *ceteris paribus* significantly reduces loan/deposit creation and ultimately real activity. Therefore, when interest rate setting follows a conventional monetary policy reaction function that responds to disinflationary shocks by lowering the policy rate, this has much more serious effects on output than away from the ZLB. The policy response needs to take this into account, either by countercyclically responding to a loans gap in addition to an inflation gap, or by permanently increasing the inflation target in order to permanently stimulate deposit creation and output. We also find that at the ZLB Phillips curves are flatter, because when lower wage and user cost inflation lead to a reduction in policy rates, this leads to credit rationing that both has an offsetting inflationary effect and a sizeable negative effect on output. The offsetting inflationary effect is due to the fact that credit rationing leads firms to raise prices, in the expectation of generating additional revenue that allows them to relax their credit rationing constraint.

The model used in this paper has been kept simple to focus on the key mechanisms at work. A key conclusion is that frictions that impede the banking system’s creation of deposit money can have large and permanent effects on the real economy. The only friction we have studied is the ZLB, but there are many other candidates, especially the many new regulations that have recently been imposed on banks. We want to use our framework to study these next, after embedding a more detailed model of the banking sector in our model.

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Table 1. Data Description

Name	Explanation	Nature of the variable
<i>Lnrealciloan</i>	Natural log of the real balance of commercial and industrial loans (USD mil)	Dependent variable
<i>cispreadnet</i>	Commercial and industrial lending spread, net of charge-offs (%)	Endogenous variable
<i>PMI</i>	Purchasing Manager Index	Candidate IV
<i>INVE</i>	Nonfinancial business investment	Candidate IV
<i>DEMAND</i>	Percentage of banks reporting stronger loan demand to large and medium firms	Candidate IV
<i>liquidity</i>	(Securities+cash+repo)/Total Assets of banks	Control
<i>supply</i>	Percentage of banks reporting tightening loan standards to large and medium firms"	Control
Δgdp	Real GDP growth rates	Control

Table 2. Estimation Results (2SLS)

First-Stage Regression

<i>cispreadnet_t</i>	Coefficient	t	P> t 	95% Confidence Interval
Δgdp_{t-1}^*	0.402	3.13	0	(0.146, 0.659)
<i>liquidity_{t-1}</i> *	-0.219	-9.01	0	(-0.267,-0.170)
<i>supply_{t-1}</i>	-0.003	-0.82	0.42	(-0.0120,0.004)
<i>DEMAND_{t-4}</i> *	0.022	8.06	0	(0.017,0.028)
<i>cons*</i>	9.166	10.51	0	(7.43,10.905)

Second-Stage Regression

<i>Lnrealciloan_t</i>	Coefficient	t	P> t 	95% Confidence Interval
<i>cispreadnet_t</i> *	0.108	4.94	0	(0.064, 0.152)
Δgdp_{t-1}^*	-0.075	-3.1	0	(-0.123, -0.026)
<i>liquidity_{t-1}</i> *	0.056	8.76	0	(0.043, 0.069)
<i>supply_{t-1}</i> *	0.003	5.03	0	(0.002, 0.004)
<i>cons*</i>	0.448	1.77	0.8	(-0.056, 0.951)

Summary Statistics

Number of Observations:	75
Adjusted R^2 :	0.703
Root MSE:	0.612

Table 3. Model Calibration

Description	Calibration	Parameter	ZLB-Constrained	Unconstrained
	Target		Value	Value
Real Policy Interest Rate (p.a.)	3%	β	0.9925	0.9925
Real Deposit Interest Rate (p.a.)	0% / 1%	κ	0.0100	0.0050
Credit Supply Elasticity	10	ξ	0.3988	0.1988
Intertemporal El. of Substitution		ϵ	0.5	0.5
Consumption Habit		v	0.75	0.75
Labor Supply Elasticity			1.0	1.0
Labor Supply	1	χ	0.3123	0.2669
Labor Income Share	60%	α	0.3242	0.3367
Investment/GDP	20%	δ	0.0171	0.0144
Government Spending/GDP	18%	\bar{g}	0.5849	0.6845
Government Debt/GDP	100%	$\bar{\tau}_L$	0.3498	0.3498
Investment Adjustment Cost		ϕ_I	2.5	2.5
Steady State Price Mark-up	10%	μ	1.1	1.1
Inflation Adjustment Cost		ϕ_p	200	200
Fiscal Debt Gap Feedback		f_b	0.1	0.1
Policy Rate Inflation Feedback		m_π	3.0	3.0
Policy Rate Loans Feedback		m_ℓ	0	0
Shock Persistence: S_t^c		ρ_c	0.70	0.70
Shock Persistence: S_t^a		ρ_a	0.95	0.95
Shock Persistence: ℓ_t^{tgt}		ρ_ℓ	0.90	0.90
Shock Persistence: S_t^{int}		ρ_{int}	0.90	0.90

Figure 1. US Inflation Rate and Unemployment Rate during Recessions (IMF WEO 2013)

(relative to first year of sample)

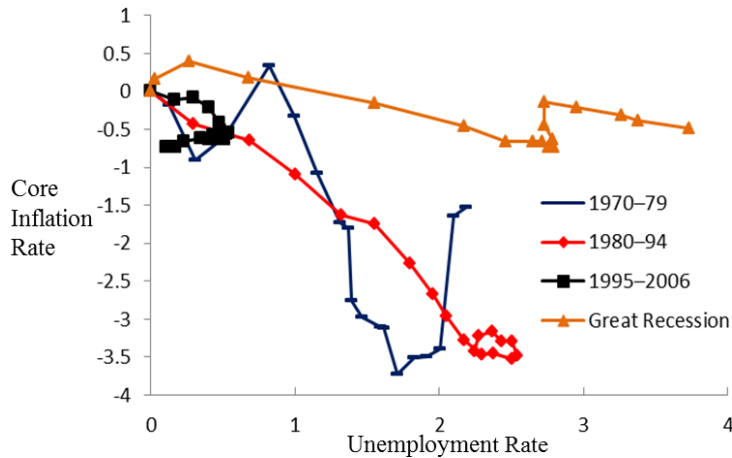


Figure 2. US Commercial and Industrial Loan Spreads

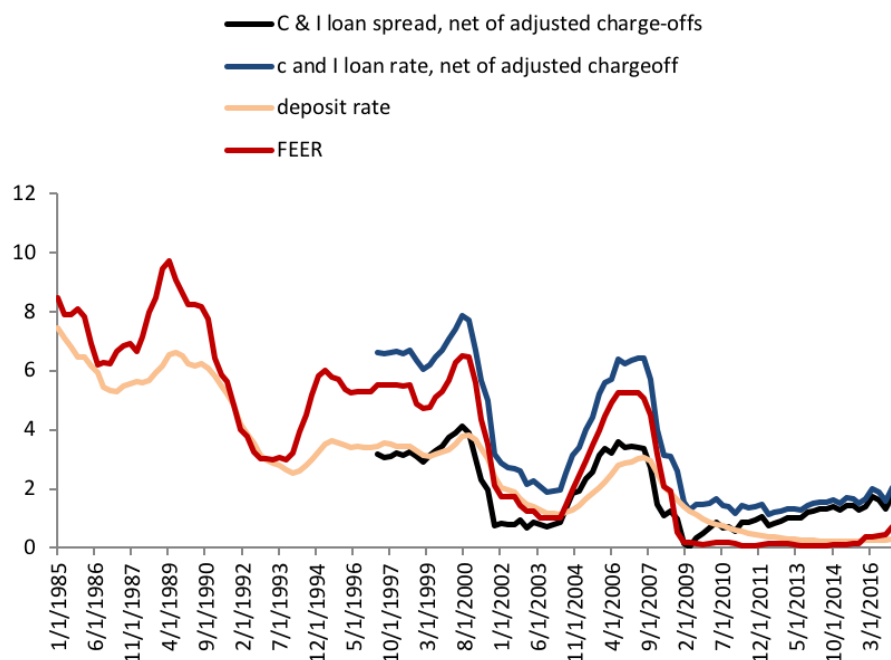


Figure 3. Timing of Intra-Period Cash Flows

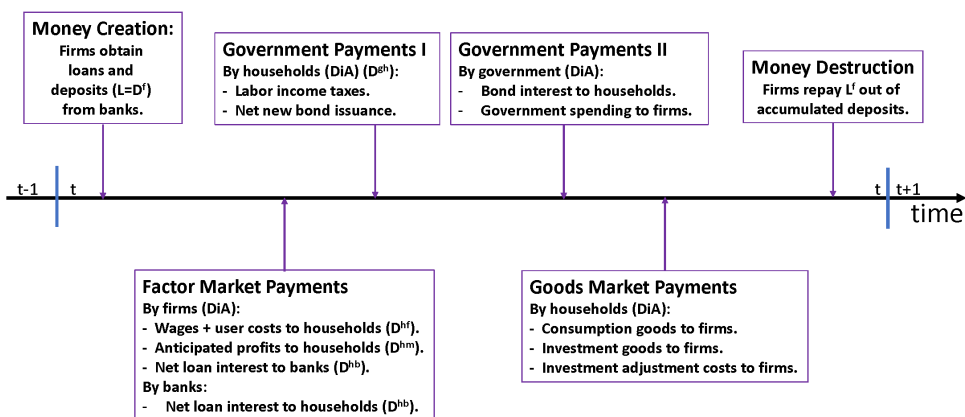
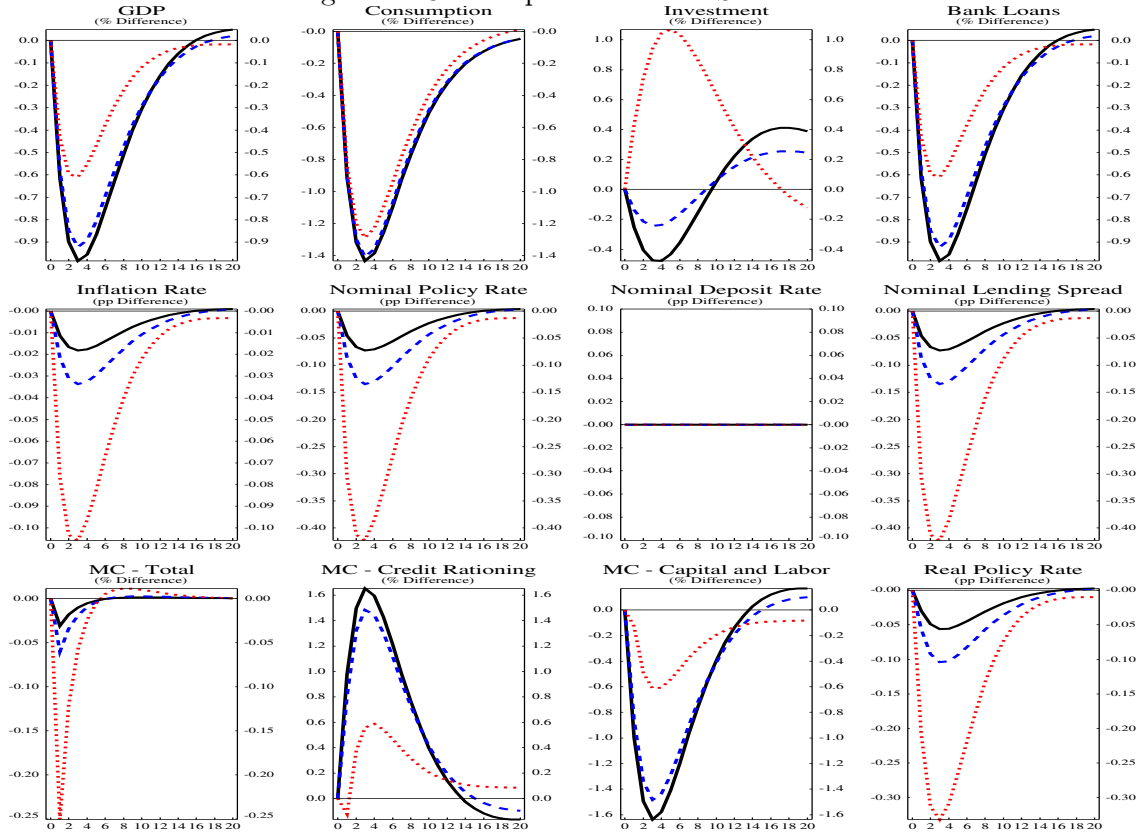


Figure 4. Consumption Demand Shock



ZLB-Constrained Economy (spread semi-elasticities: solid = 10 / dashed = 5 / dotted = 1)

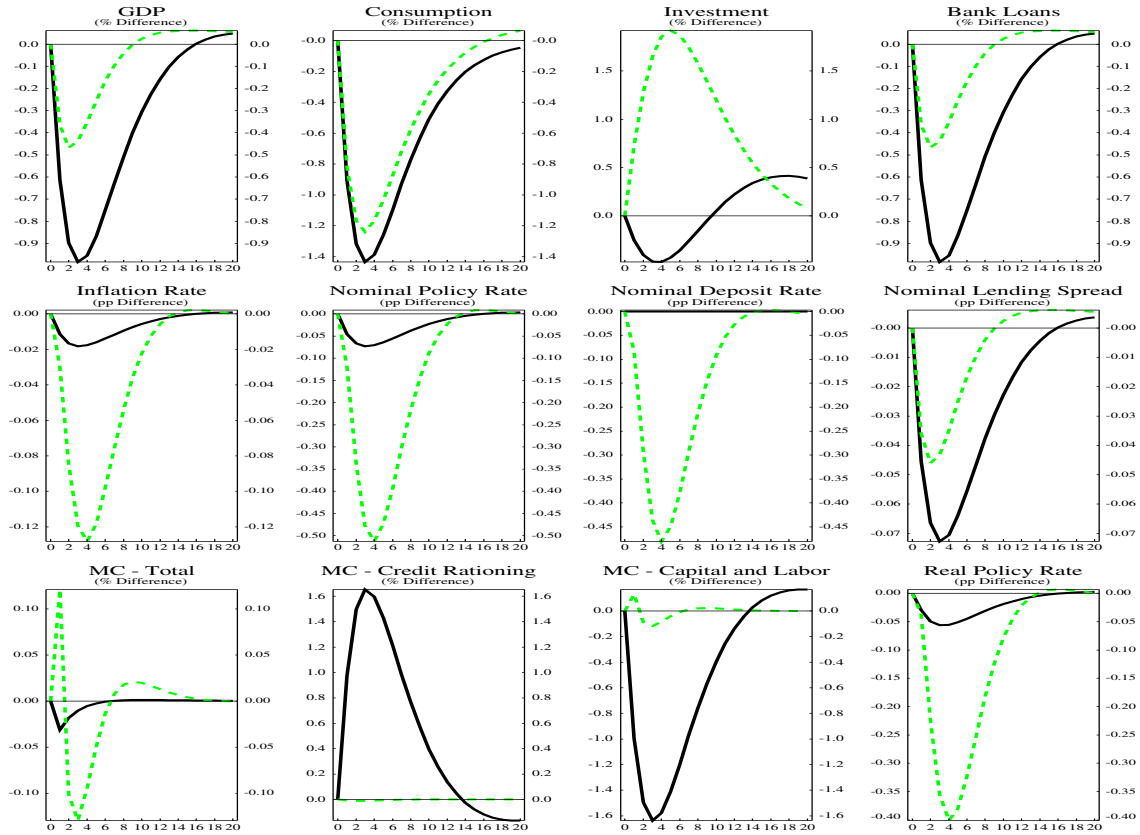
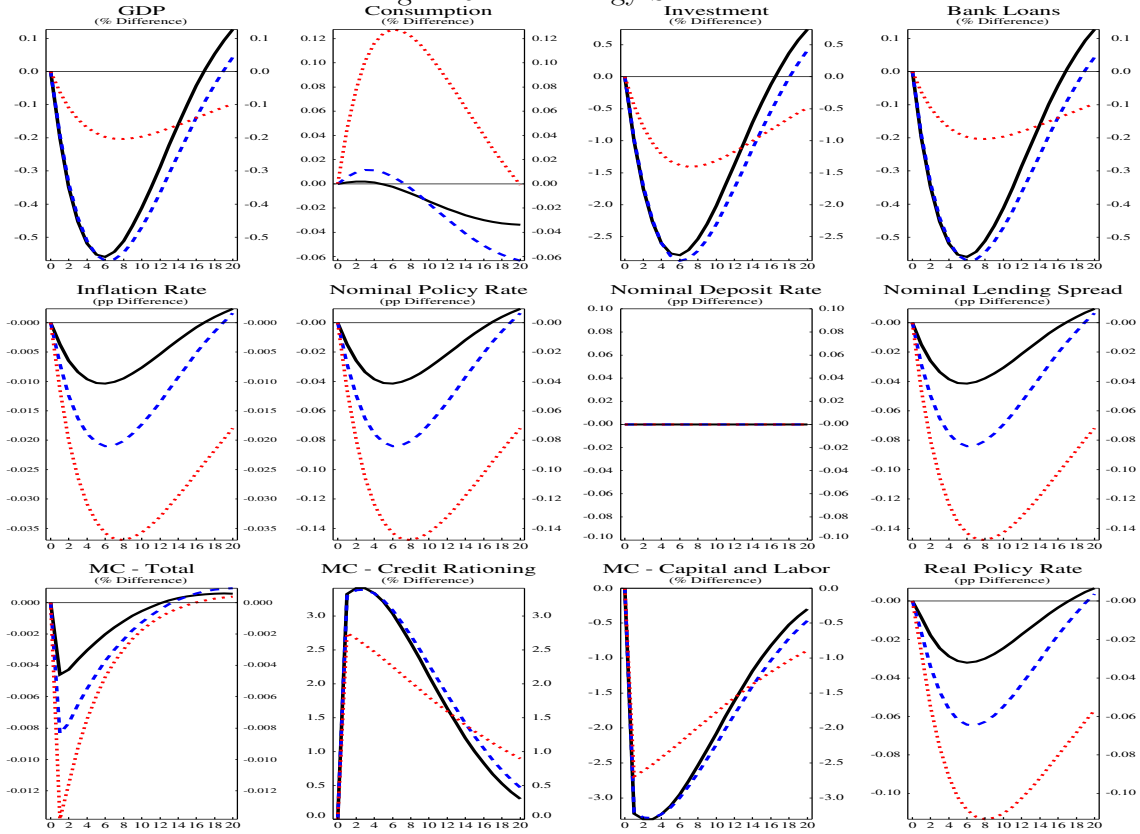


Figure 5. Technology Shock



ZLB-Constrained Economy (spread semi-elasticities: solid = 10 / dashed = 5 / dotted = 1)

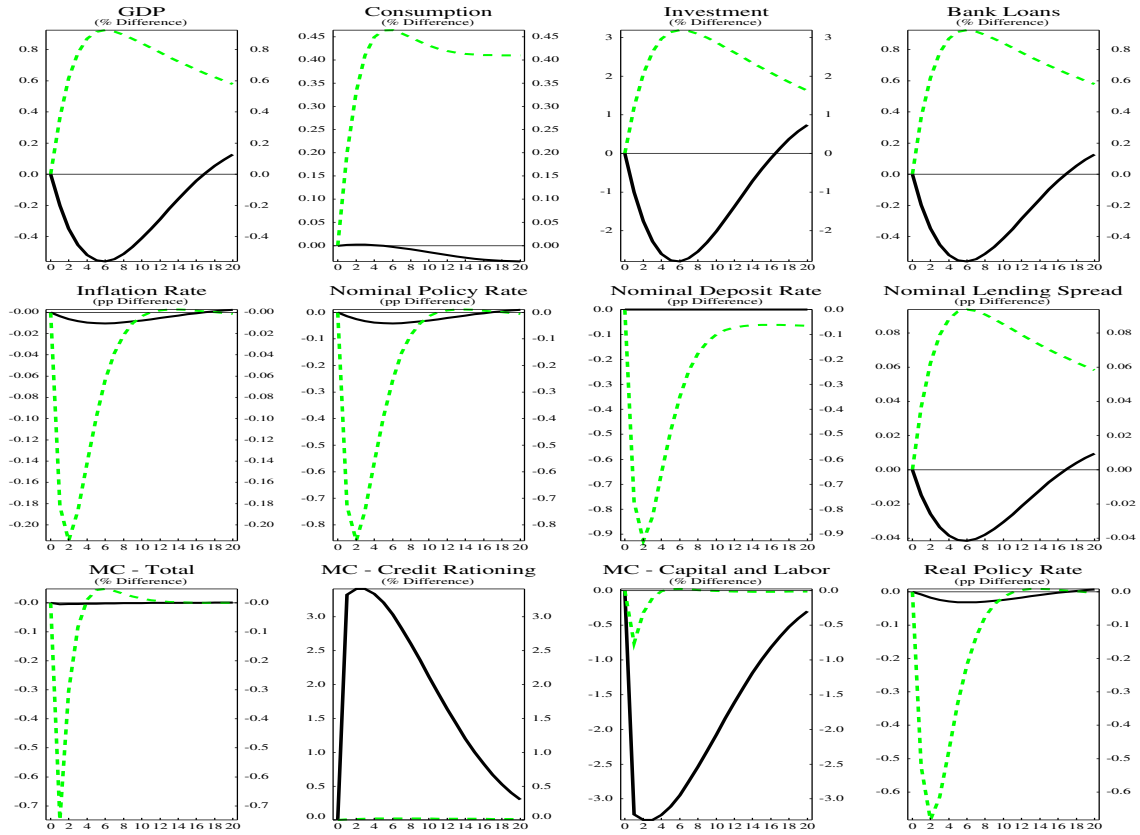
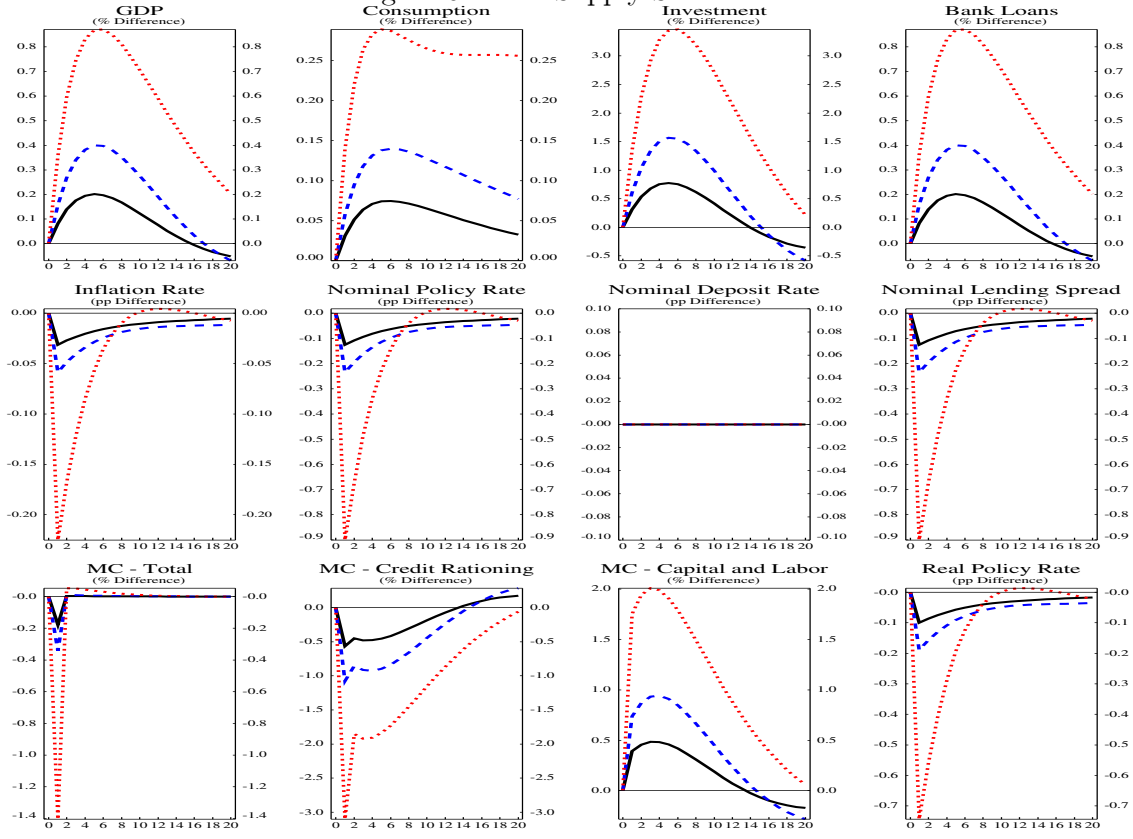


Figure 6. Loan Supply Shock



ZLB-Constrained Economy (spread semi-elasticities: solid = 10 / dashed = 5 / dotted = 1)

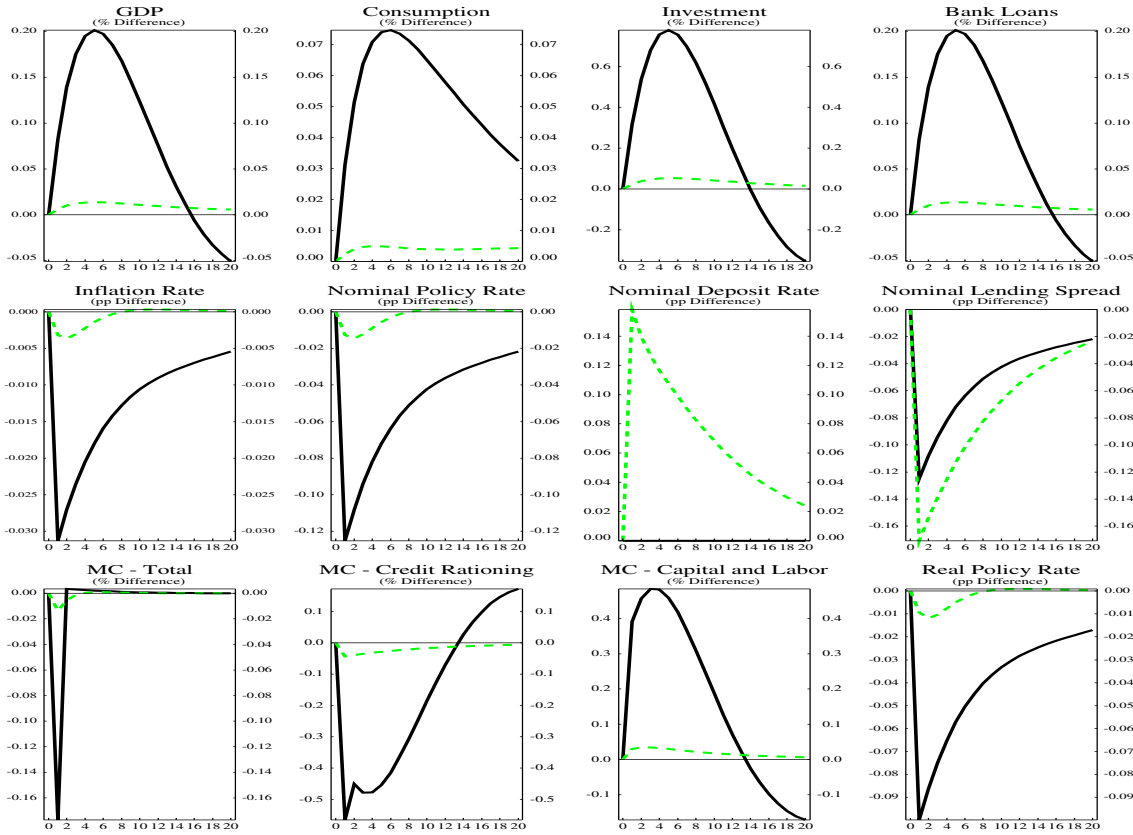
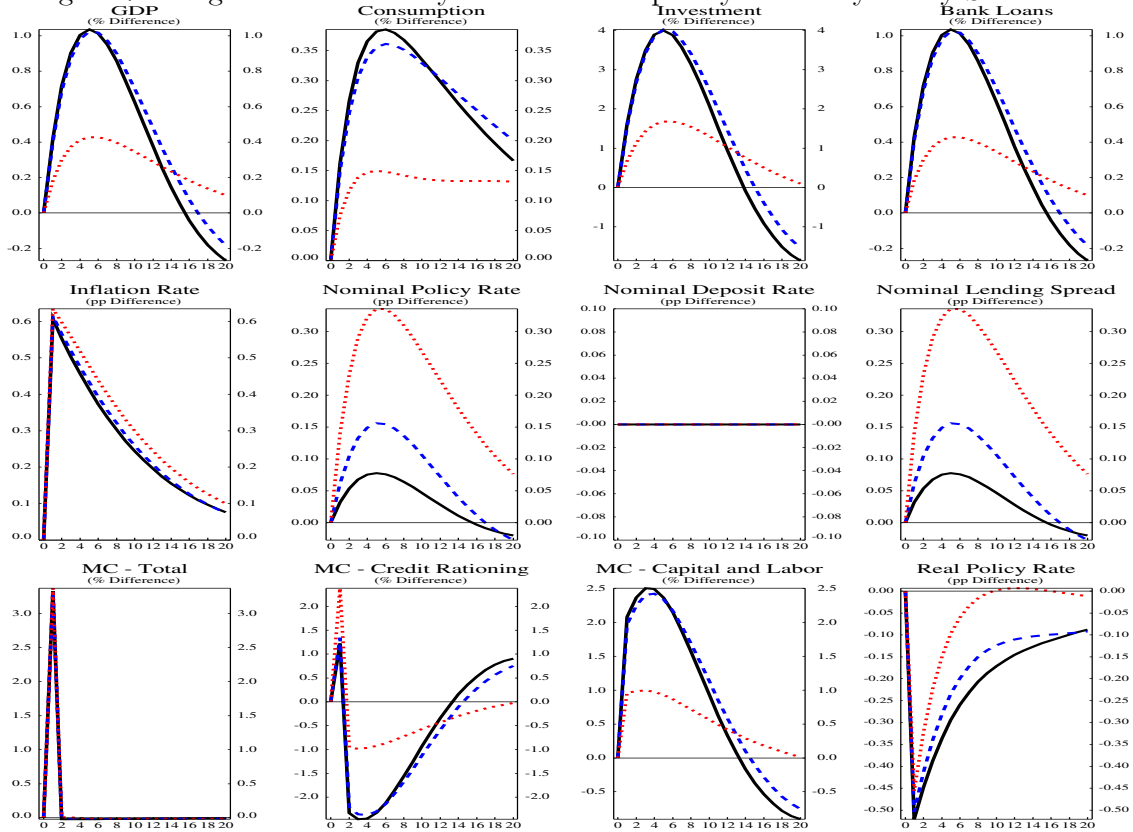


Figure 7. Exogenous Inflationary Policies I: Temporary Monetary Policy Shock



ZLB-Constrained Economy (spread semi-elasticities: solid = 10 / dashed = 5 / dotted = 1)

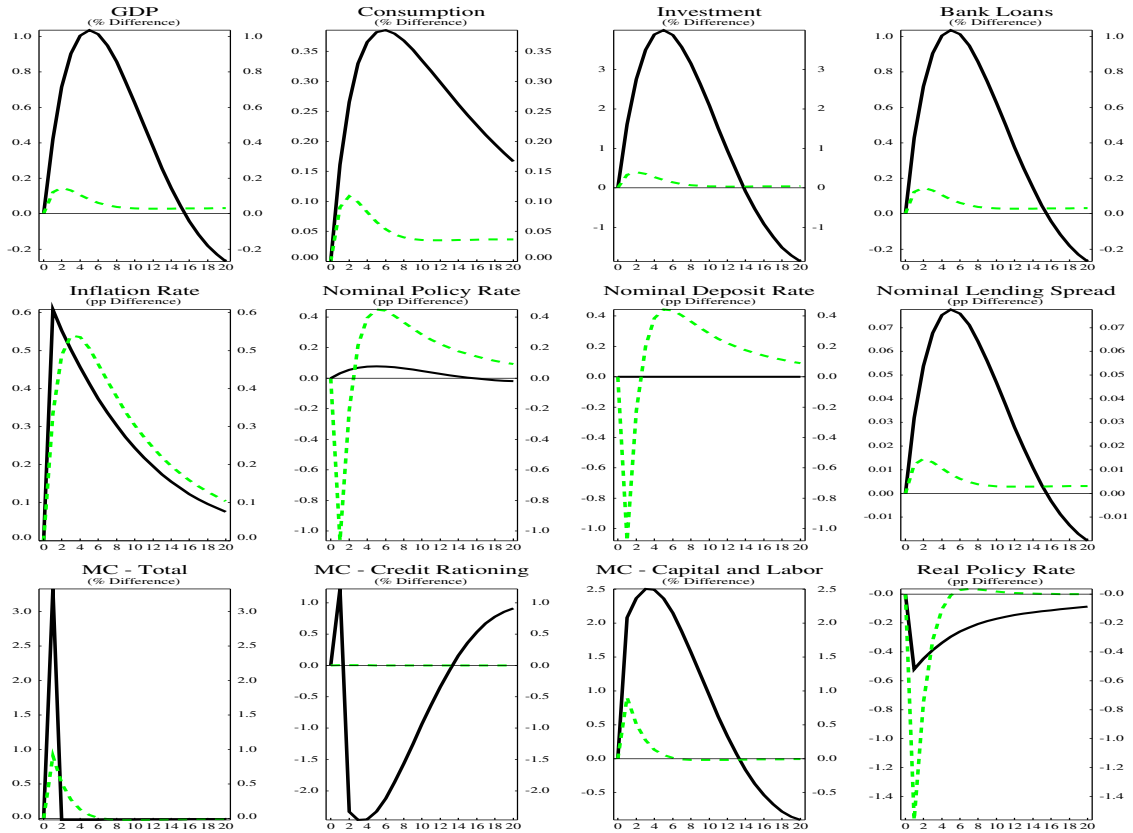
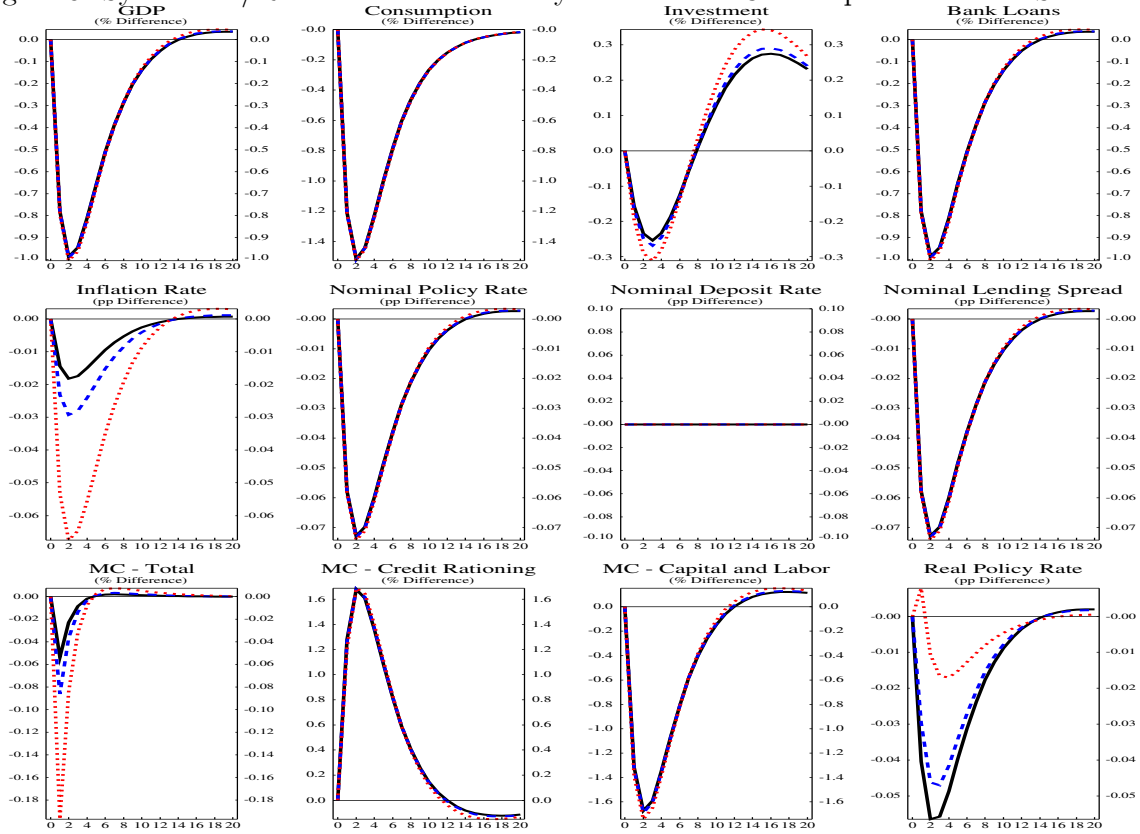
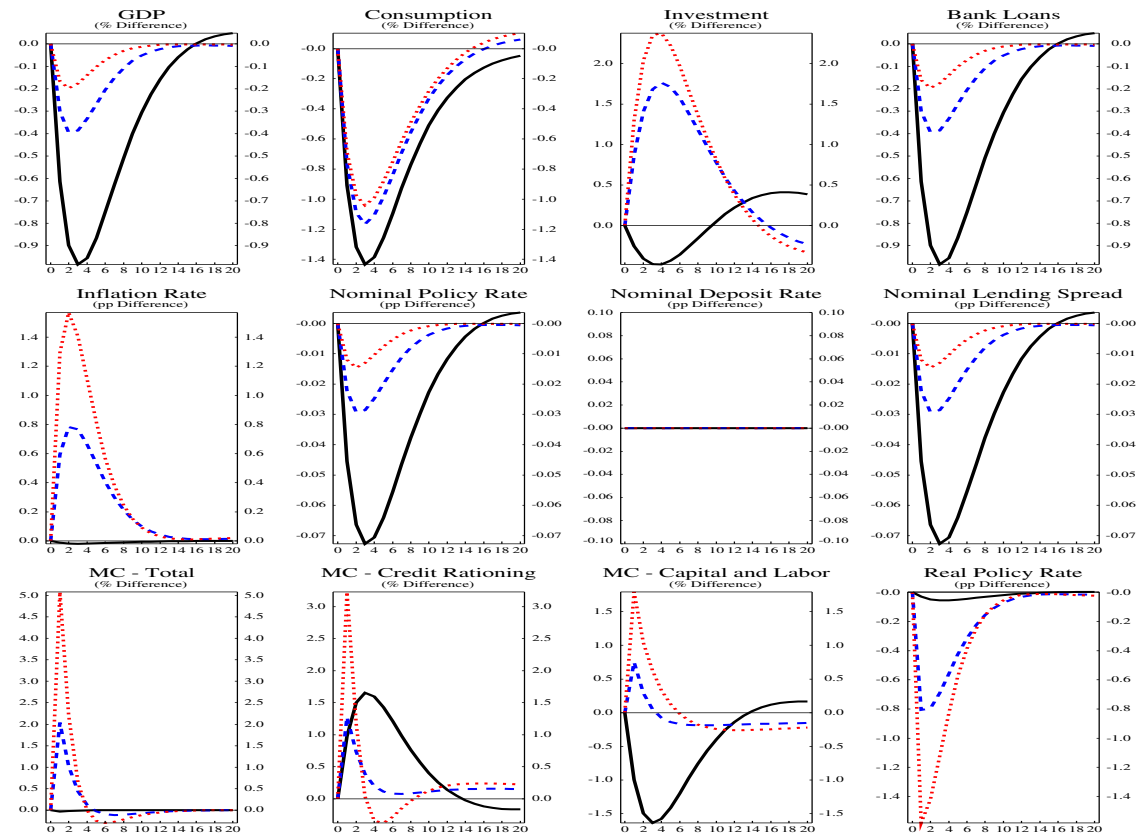


Figure 8. Systematic/Rules-Based Inflationary Policies and Consumption Demand Shock

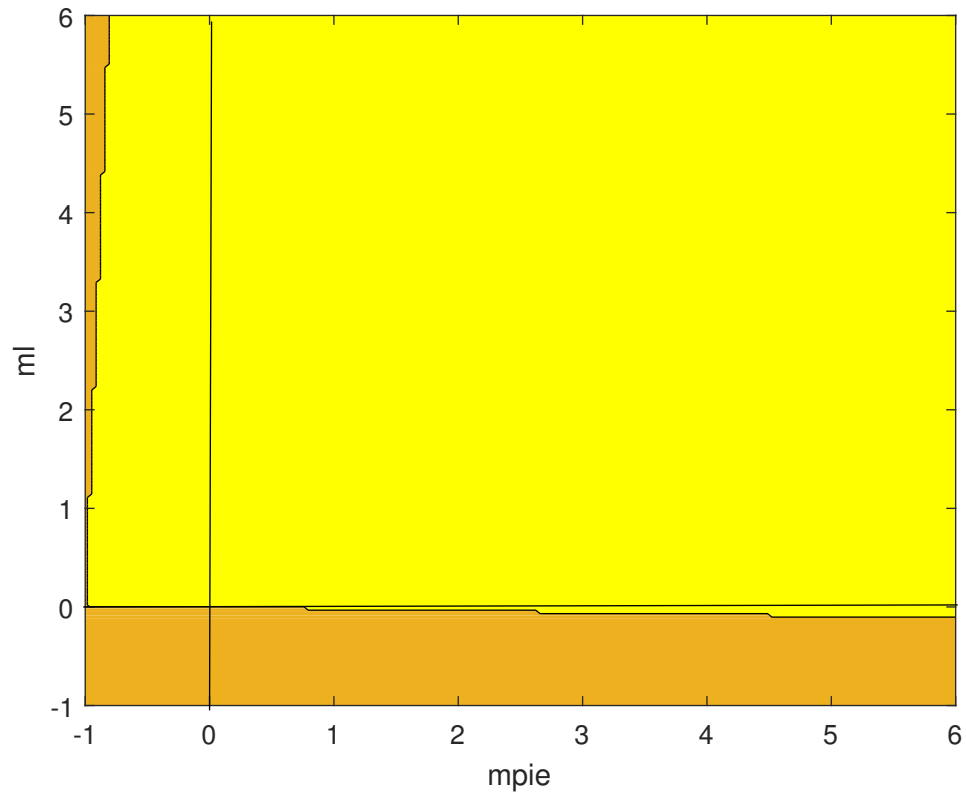


ZLB-Constrained Economy - Weaker Inflation Response: m_π : solid = 3 / dashed = 1.5 / dotted = 0.1

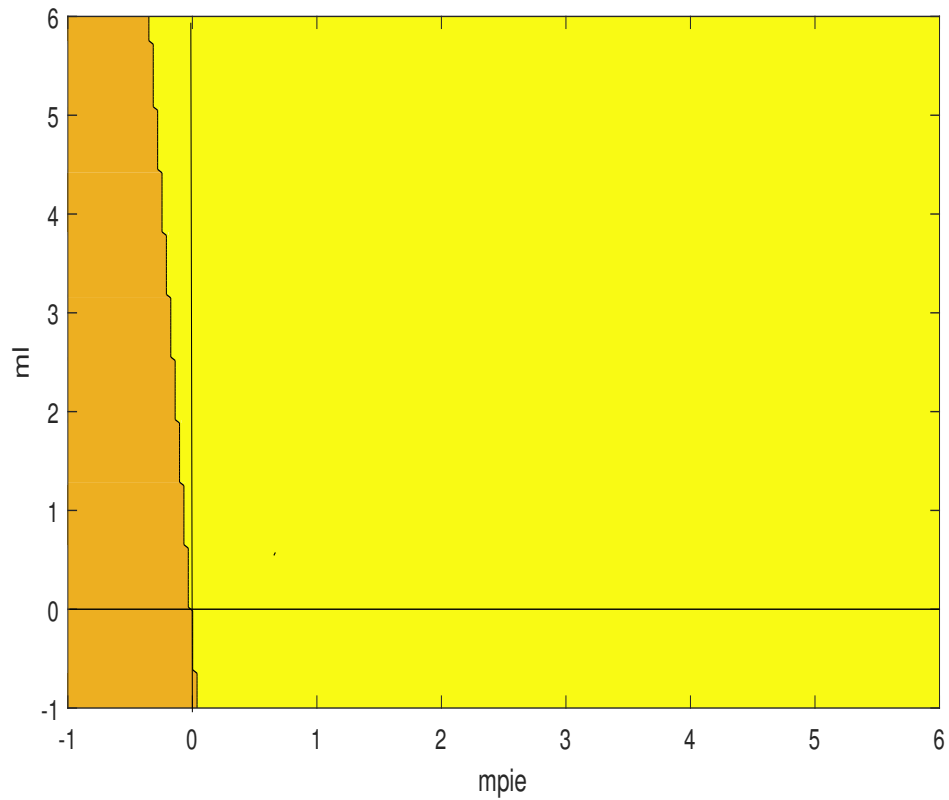


ZLB-Constrained Economy - Stronger Credit Response: m_ℓ : solid = 0 / dashed = 2 / dotted = 8

Figure 9. Determinacy Regions for ZLB-Constrained and Unconstrained Economies

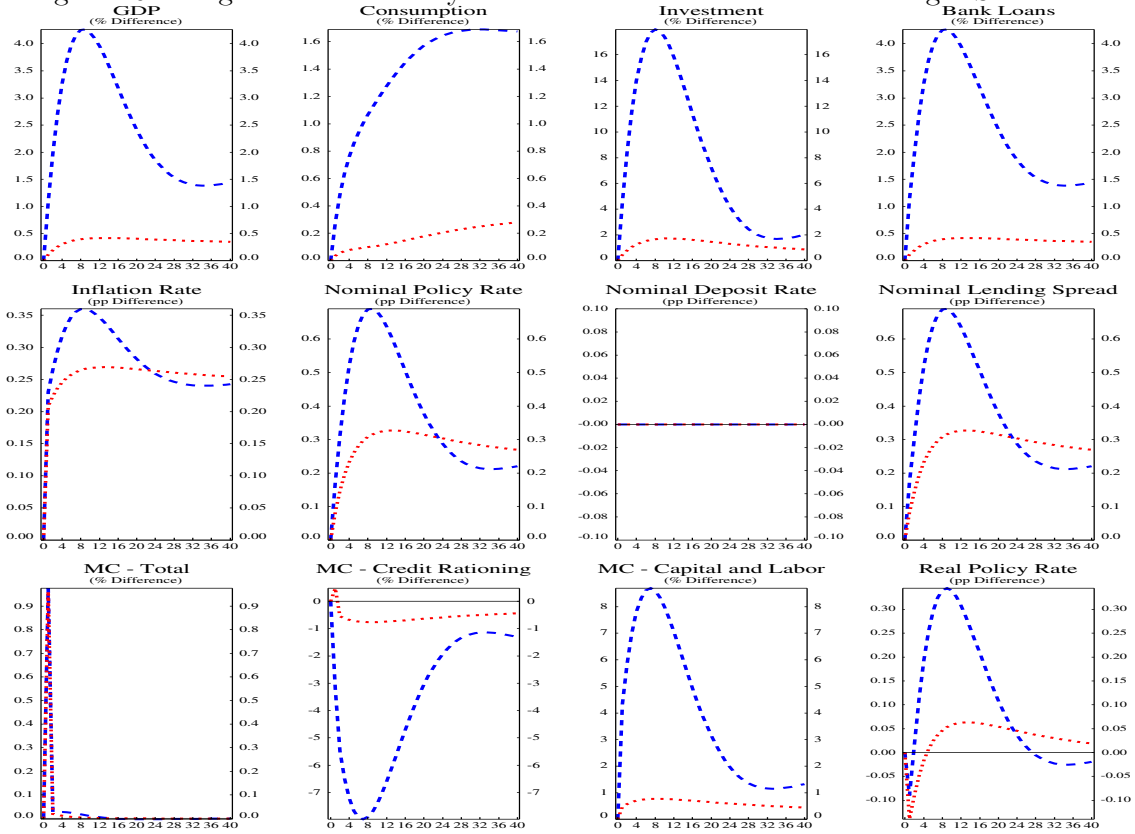


ZLB-Constrained Economy - Spread Semi-Elasticity = 10 (yellow = BK-stable)



Unconstrained Economy - Spread Semi-Elasticity = 10 (yellow = BK-stable)

Figure 10. Exogenous Inflationary Policies II: Permanent Inflation Target Shock



ZLB-Constrained Economy (spread semi-elasticities: solid = 10 / dashed = 5 / dotted = 1)

