

Banks, Money and the Zero Lower Bound on Deposit Rates

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Abstract

We study a New Keynesian model where banks create deposits through loans, subject to increasing marginal cost of lending, and where all non-banks must use deposits to make payments. We discuss three implications. First, non-banks do not face budget constraints but deposits-in-advance constraints, and both individual and aggregate purchasing power can be increased beyond prior income through ex-nihilo deposit creation. Second, at the ZLB on deposit rates (ZLBD) further policy rate reductions reduce spreads, and thereby reduce bank profitability, deposit creation and output. Third, at the ZLBD Phillips curves are flatter because credit rationing is both contractionary and inflationary.

Keywords: Banks, money creation, money demand, deposits-in-advance, Phillips curve, zero lower bound.

JEL Codes: E41, E44, E51, G21

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1. Introduction

This paper is a contribution to the literature on the role of banks in the macro-economy. We propose a modeling framework in which the key function of banks is the creation of deposits through loans, and where deposits serve as the economy’s universal medium of exchange, without which neither production nor consumption would be possible. We then show that when the willingness of banks to create deposits depends on the credit spread between loan and deposit interest rates, the zero lower bound on deposit rates (ZLBD) has sizeable effects on deposit creation and output, reductions of the policy rate are contractionary, and Phillips curves are flatter than away from the ZLBD. We conclude by proposing two modifications of the policy rule that could address this problem.

The conceptual and modeling framework that is almost universally used in the current banking literature is the *loanable funds model*, which represents banks as intermediaries of physical resources akin to warehouses. Specifically, as we will demonstrate below, in this model class banks do not intermediate financial balances, but instead literally collect deposits of physical resources from savers before lending them to borrowers. Although it is understood that this is a modelling shortcut, it is counterfactual, and this affects how the model represents the transmission of economic shocks through financial markets. In actual financial markets, as explained in a long and growing list of publications by central banks and academia that we will reference below, it is instead the extension of new loans themselves that creates new deposits, with all physical resource trading taking place outside the banking sector. This deposit money is demanded by all agents in the economy because it represents the principal medium of exchange. The aim of the present paper is to present an infinite horizon New Keynesian *financing model* that captures this mechanism. The model explicitly represents the deposit-based economic exchanges between different non-bank agents, and thereby goes beyond other financing models such as Jakab and Kumhof (2015, 2019), where a single representative non-bank agent requires bank deposits because of a transactions cost technology (or a deposits-in-advance constraint). In our model banks are therefore indeed intermediaries between different agents, but they intermediate between different spenders of deposit money rather than between savers and borrowers of physical resources.

Our choice of a financing model over the alternatives is driven by a desire to achieve a realistic representation of the lending process, and to rule out, *a priori*, representations that are clearly at variance with this process. This is a consideration that should precede any empirical comparisons. But of course the data can and should be studied, and the stylized facts of four major advanced economies studied in Jakab and Kumhof (2019) provide further support for our choice.¹ Specifically, aggregate banking sector balance sheets exhibit very large and rapid quarter-on-quarter changes, and loanable funds models, in order to rationalize these observations, must rely on a combination of changes in deposits of physical savings, in net purchases by banks of physical capital or of securities that represent claims to physical capital, and in valuations of banks’ asset portfolios. However, these mechanisms are shown to only play a negligible role in aggregate financial system data. Financing models on the other hand have no difficulty in accounting for the observed volatility of bank lending, and also for periods of sustained lending growth in excess of GDP growth or of national saving.²

¹Deleidi and Levrero (2019) study the US money creation process using VAR and VECM methods and find strong evidence for the financing mechanism. Bayesian estimation of a financing model is work in progress.

²Mian and Sufi (2014) argue that excessive credit supply growth was a key reason for the crisis of 2008.

The resulting approach sees the creation and destruction of deposit money by banks, and therefore the determination of the size of bank balance sheets, as the outcome of the simultaneous solution of the profit maximization problems of banks and their customers. As such it is consistent with the credit mechanics approach to bank balance sheets that is reviewed and advocated in Decker and Goodhart (2018).³ Importantly, financing models can directly incorporate the many advances that have recently been made in the modelling of banks, because the distinctive feature of financing models is not found in the optimization problems of banks but in the budget constraints, or rather the deposits-in-advance constraints, of their customers. Our own model of bank optimization is kept deliberately simple, but the logic extends to more complex set-ups.

The two key insights underlying all financing models are, first, that deposits of financial instruments at financial institutions neither put additional loanable funds at their disposal nor increase the size of the financial system's consolidated balance sheet, and second, that new loans are funded by the creation of new bank deposits and therefore do increase the size of the financial system's balance sheet. We will now discuss each of these in more detail.

First, we study a representative 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, which collects the check. 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, they are not new funds, no new deposits are created. 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.⁴ Furthermore, cash is a minor and non-constitutive element of modern financial systems. Because the creation of new deposits in loanable funds models can therefore not represent the deposit of financial instruments, it must represent the only remaining alternative, the accumulation of physical resources. That this is indeed the case can be verified directly in the (stylized) budget constraints of banks' depositors in loanable funds models, where changes in deposits Δd_t equal the difference between physical incomes and physical expenditures of savers (superscript s) $inc_t^s - exp_t^s$, a difference that represents the physical accumulation, and then intermediation by way of bank loans, of physical resources. A similar budget constraint applies to borrowers (superscript b), who experience changes in loans $\Delta \ell_t$. We have

$$\begin{aligned} \Delta d_t &= inc_t^s - exp_t^s, \\ -\Delta \ell_t &= inc_t^b - exp_t^b, \end{aligned} \tag{1}$$

where we abstract from trading in physical capital or securities between banks and non-banks, which as explained above plays only a very small role in the data. The change in banks' balance sheet is for simplicity assumed to be $\Delta \ell_t = \Delta d_t$.

³This approach was popular in Germany in the 1920s-1960s, and several of its leading proponents became high-ranking Bundesbank officials. Key references include Hahn (1920), Gestrich (1936), Lautenbach (1952), Rittershausen (1956) and Stützel (1958).

⁴Overdrafts are not an exception. An overdraft permits the creation of new bank deposits on demand. A newly created deposit can then be instantaneously withdrawn in the form of a check or cash.

Second, we study a representative loan transaction. 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 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. In other words, the loan is financed through money creation. Only banks have this ability, because only banks are perceived to be able to credibly commit to honoring 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, or money. The main reason is explicit or implicit public support for banks. In fact, the entire system of central banks and regulatory agencies was constructed with this as its original objective, because trust in the nation’s main medium of exchange has always been considered critical for the performance of the economy (Goodhart (1988)). 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 deposits are risk-free, and are the only circulating medium of exchange. We also assume that bank loans are non-defaultable. This keeps the emphasis away from bank asset-side considerations and instead adopts an exclusive liability-side focus, in other words an exclusive focus on the monetary dimension of banks’ activity. A (stylized) representation of the financing model in terms of the constraints facing a representative non-bank agent (superscript r) is

$$\begin{aligned} \Delta d_t - \Delta \ell_t &= inc_t^r - exp_t^r, \\ d_t &\geq exp_t^r, \end{aligned} \tag{2}$$

where the change in banks’ balance sheet is again given by $\Delta \ell_t = \Delta d_t$. The first of these equations, the budget constraint, therefore simply states that deposits are created through loans rather than through physical resource accumulation, while expenditure has to equal income.⁵ The second equation is the deposits-in-advance constraint, and this limits expenditure not in terms of physical resources but in terms of digitally created purchasing power.

We emphasize that once a newly created deposit has been paid to a recipient, this does not make the recipient a saver. First, the vast majority of loans, including working capital loans as in this paper, do not finance physical investment⁶ and therefore have no connection to physical saving. Second, deposits cannot be meaningfully interpreted as interpersonal saving when they continue to circulate, again as in this paper, to facilitate further payments among multiple recipients.

This 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-maximizing and risk-minimizing creation and destruction of ledger entries.⁷ 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 papers by the Bank of England (McLeay et al. (2014a,b)), from numerous papers by the Bank for International Settlements (see e.g. Borio and Disyatat (2011,

⁵In a model with capital accumulation the difference between income and expenditure equals the change in capital.

⁶In most major economies well under half of variations in total credit to the nonfinancial private sector is accounted for by loans to nonfinancial business, of which in turn the major portion relates to the financing of activities that are not related to saving. See Bezemer et al. (2017).

⁷This 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.”

2015)), from reports by the Bundesbank (Bundesbank (2017)) and the Reserve Bank of Australia (Doherty et al. (2018)), and from the above-mentioned paper by Decker and Goodhart (2018). DSGE representations of this process are now also beginning to find their way into the models of central banks and policy institutions, including the International Monetary Fund (Benes et al. (2014a,b)), Central Bank of Ireland (Lozej et al. (2017), Lozej and Rannenberg (2017)), Lithuanian Central Bank (Ramanauskas and Karmelavičius (2018)), Norges Bank (Kravik and Paulsen (2017)) and People's Bank of China (Sun and He (2018)).⁸

It is important to emphasize 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 non-bank financial institutions (NBFIs). As shown in Pozsar (2014), NBFIs are not creators of money but intermediaries of bank-created money. Banks are the central actors in the 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. From this perspective⁹ it is therefore legitimate to model the overall financial system as consisting entirely of banks.

Recent models of monetary economies have increasingly omitted monetary aggregates altogether, as also argued in Piazzesi and Schneider (2018) and Bianchi and Bigio (2014). Such models instead adopt the so-called cashless limit assumption whereby the transmission of monetary policy can be thought of exclusively in terms of interest rates. This abstraction renders money and financing through the banking sector irrelevant. By contrast, the preceding model generation, which is sometimes referred to as Sidrauski-Brock (SB) models¹⁰, and which is still commonly used today, had a central role for money. Financing models are best classified as a further development of SB models. In this context two typical features of the original SB models are important. First, private agents hold money because of a money demand that is generated by either a cash-in-advance constraint, money in the utility function or a transactions cost technology. Second, the only money in these models is government fiat money, while banks are either omitted altogether or modeled as intermediaries of physical resources. A large and seminal literature has since arisen to improve upon the first feature (see e.g. Gu et al. (2013), Lagos et al. (2017) and the many references cited therein). This literature often retains the assumption of government fiat money, in combination with private real credit and private commodity money, but generally not with deposit money created through loans as in financing models. We mention this literature only briefly, because it has a different focus from the financial cycle and business cycle issues that concern us. Our work can instead be seen as an attempt to improve upon the second feature of SB models. Our motivation is that in modern economies government fiat money accounts for only a very small fraction (3% in the case of the UK) of the broad money supply, with the liabilities of private financial institutions accounting for the remainder (97%).¹¹ The key feature of financing models relative to SB models is to have these 97% rather than the 3% enter the money demand function, and to present the optimizing calculus according to which banks and their customers decide on the creation of that money. Because in our model bank deposits are effectively riskless in nominal terms, they serve

⁸There is also an important literature from leading legal scholars that explains the nature of banks as creators of money. See e.g. Desan (2014), Ricks (2018) and Hockett and Omarova (2017). The latter make the same points as this paper, but of course from a legal rather than an economic perspective.

⁹Of course for the study of many other questions a split of the financial system into banks and NBFIs can be a critical part of the analysis.

¹⁰See Sidrauski (1967) and Brock (1975).

¹¹Furthermore, under inflation targeting and away from the zero lower bound, the quantity of government fiat money is itself endogenous rather than exogenous. The reasons are discussed below.

the same functions as government fiat money in older SB models. The difference is therefore not in the function or risk properties of money, but only in the manner of its creation.

This paper introduces a bank-based monetary transactions mechanism into an otherwise standard environment. It does so by using a sequence of deposits-in-advance constraints that cover every single payment in the economy.¹² Simplifying for the purpose of exposition¹³, at the beginning of each period loans are made to firms in order to create deposits for firms. The deposits are used to make two sets of payments inside the period. The first is payments for labor and other inputs from firms to households to pay for the production of output, and the second is payments from households to firms to pay for the purchase of that output. The second set of payments enables firms to extinguish the loans at the end of the period, for one instant. The same process then repeats in each following period. There is an important difference between this approach and traditional cash-in-advance models. In the latter, the cash requirement only covers one class of transactions, while agents still face an overall budget constraint that is in terms of physical resources. This implies that all other transactions are carried out using non-monetary exchange.

Our approach of combining loan-based deposit creation with deposits-in-advance constraints that cover all transactions therefore demonstrates more clearly why bank financing is so critical. Non-bank agents that have access to bank credit are never constrained by a budget constraint that limits their purchasing power to their prior income as in (1), but instead by a deposits-in-advance constraint that limits their purchasing power to their deposits, which in turn equal the sum of their prior income and net new deposit creation, as in (2). Prior income can be used to make purchases because it is received in the form of bank deposits. But bank deposits can also be created through additional loans, independently of prior income, requiring only book entries and no physical resources. By contrast, in loanable funds 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 physical savings changes hands between them, through the agency of banks. Our 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 mobilization of additional resources that would otherwise have remained idle. This increases real incomes, especially when the economy is financially constrained. And to the extent that it does not increase real incomes, it increases inflation.

Our model studies the implications of a specific financial constraint, the ZLBD. Our concern is not per se with the level and therefore the zero lower bound on the policy rate (ZLB), but rather with the effect of changes in the policy rate on banks' lending and deposit rates and therefore on their net interest margin, which in turn affects their incentives to lend. Net interest margins are not directly affected by the ZLB but rather by the ZLBD, and there is generally further scope to lower the policy rate once the ZLBD has been reached. The fact that the ZLBD, especially on retail deposits, has indeed been an effective constraint in several low-interest economies is documented in Bech and Malkhozov (2016) and Heider et al. (2017)¹⁴, and the empirical literature has shown that this has had negative consequences for bank profitability and lending. Section 2.3 contains additional references.

¹²Our 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).

¹³We abstract from payments to and from banks (interest) and government (taxes, spending and bond purchases).

¹⁴The ZLB, as evidenced by negative policy rates in a number of countries, appears to be a softer bound.

To illustrate this concern, our theoretical model compares the behavior of the ZLBD-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 ZLBD deposit interest rates can no longer adjust, and any change in the policy rate, which leads to a one-for-one change in banks' lending rates, leads to a change in spreads that changes banks' ability to cover the cost of making loans, and therefore to a change in the creation of loans and deposits. In this case the volume of loans is primarily driven by changes in net interest margins rather than by changes in credit demand.

In this ZLBD-constrained environment higher policy interest rates are expansionary. Specifically, because banks' profit margins depend on nominal credit spreads, a permanent increase in the nominal policy rate that does not depart from the fundamental level of the real interest rate, 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 policy rates are 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 credit spreads to deposit creation to economic exchange to real activity, is new.

Furthermore, in the ZLBD-constrained environment the drivers of inflation include not only traditional marginal cost terms but also the multiplier of a credit rationing constraint. Based on our empirical estimates, the supply of credit is highly responsive to credit spreads, and this means that disinflationary demand and supply shocks, if accompanied by a drop in the policy rate, are characterized not only by a drop in traditional marginal cost terms but also by tighter credit rationing. The latter has an inflationary rather than a deflationary effect, because credit rationing induces producers to charge higher prices, given that higher sales revenue allows them to relax their credit rationing constraint. This offsetting effect implies that the inflation response to shocks near the ZLBD is much more subdued than away from the ZLBD, while the output response is significantly amplified. In other words, the Phillips curve is much flatter near the ZLBD.

We also emphasize another key feature of our model, the endogenous strong comovement between consumption and investment at the ZLBD. The reason is that at the ZLBD the overall quantity of deposits is constrained, with scarce deposits being required for the purchase of both consumption and investment.

We have so far discussed two models of banking, the loanable funds and the financing model. Discussions of banking still frequently appeal to a third model class, the deposit multiplier model. This argues that the size of bank balance sheets is a multiple of the policy-determined quantity of central bank money, with the latter being either a constraint on credit creation or on repeated re-lending by banks. This model does not take into account that central bank money, as discussed above, either cannot be (reserves) or is not (cash) lent to nonbanks. But more importantly it ignores that, away from the zero lower bound, modern central banks invariably target interest rates, and are committed to supplying as much central bank money as banks demand at that rate.¹⁵ The quantity of reserves is therefore not a determinant of private money creation in the sense of the deposit multiplier model. This argument has been made repeatedly in publications of the world's

¹⁵As shown by Kydland and Prescott (1990), the availability of central bank money also did not constrain bank lending during the period when the Federal Reserve officially targeted monetary aggregates. The same is true, for different reasons, under quantitative easing at the zero lower bound.

leading central banks, and also, supported by recent experience, in Decker and Goodhart (2018). Therefore, as long as monetary policy is modelled as following a Taylor-type interest rate rule, the nominal as well as real quantities of cash and reserves must be treated as demand-determined, which implies that they cannot be used as an independent policy instrument. Our model assumes such an interest rate rule, with active monetary and passive fiscal policy in the terminology of Leeper (1991), and this implies that the model can, without loss of generality, abstract from central bank money altogether. Instead all money is deposit money, whose quantity is determined by the interaction of the profit-maximizing decisions of banks and their customers.

The price level is nevertheless determinate because of sticky price inflation following Ireland (2001). Calvo (2012, 2016) argues that government fiat money derives its liquidity and positive purchasing power from the existence of sticky prices, which provide an output backing to money. He terms this the price theory of money, and traces its origin back to Keynes' General Theory. But our model goes further in that banks optimally decide on the real rather than the nominal quantity of money issuance at the beginning of each period, and this deposit money, unlike government fiat money, is self-liquidating through loan repayment at the end of each period. This ensures that the purchasing power of deposit money over physical resources cannot be inflated away before its liquidation. Deposit money therefore serves the function of a medium of exchange in the same way as government fiat money in Sidrauski-Brock models, but unlike the latter it does not serve as a nominal anchor.

The financing model of this paper enables us to use a strictly financial (non-physical) perspective on bank balance sheets to study important contemporary monetary issues, with novel results on the distinction between income and purchasing power and on the ZLBD. We view this as an important step to help to connect the study of monetary and financial issues, and thereby help to open up a fruitful agenda for future research.

The rest of the paper is organized as follows. Section 2 reviews the related theoretical and empirical literatures. Section 3 presents empirical evidence on the semi-elasticity of credit supply with respect to credit spreads. Section 4 develops our theoretical model. Section 5 studies illustrative simulations based on this model. 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 aggregate income and aggregate purchasing power. Section 2.3 reviews the literature on contractionary reductions in nominal policy interest rates in low-interest economies. Section 2.4 reviews the literature on the flattening of the Phillips curve.

2.1. The Theoretical Macro Literature on Banking

In this section we review the recent theoretical macro literature on banking.¹⁶ For convenience we divide our review into two parts, recent New Keynesian DSGE models and macroeconomic theory

¹⁶An 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.

models with banks that are modelled, wholly or at least in part, in accordance with the financing model. Because this literature is large, the list of papers is necessarily incomplete.

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. 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 and modelled as loanable funds banks. 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).

2.1.2. Macroeconomic Theory Models with Financing Banks

Other than the work at central banks and Jakab and Kumhof (2015, 2019)¹⁷, which were cited in Section 1, to our knowledge only three macroeconomic theory papers, Goodfriend and McCallum (2007), Faure and Gersbach (2017) and Clancy and Merola (2017), are based exclusively on the financing model of banks. In Goodfriend and McCallum (2007) loans create deposits that enter a deposits-in-advance constraint on consumption. Their work differs from ours in several dimensions. First, banks interact with a representative household rather than intermediating payments between households, firms and government. Second, all transactions other than consumption are carried out using physical resources, so that for their overall expenditure households still face a budget constraint rather than a deposits-in-advance constraint. This makes it harder to discuss the difference between income and purchasing power that is at the heart of some key results in our paper. Third, while deposits themselves do not represent physical resources, a role for physical resources is reintroduced into the model because loans are produced using a Cobb-Douglas production function in capital (as collateral, together with bonds) and labor, which gives impulse responses a strong real flavor, akin to a manufacturing firm, that is absent in our model. Faure and Gersbach (2017), in a 2-period model, show that in the absence of uncertainty financing models imply identical allocations to loanable funds models. This is related to the result in Jakab and Kumhof (2015, 2019) that the deterministic steady states of the two model classes are identical. Finally, Clancy and Merola (2017) study macroprudential policies in small open economies in a variant of the financing model of Benes et al. (2014a,b).

In another part of the recent literature the financing function of banks plays a role, however it does so alongside other mechanisms. The 3-period model of Donaldson et al. (2018) is based on a combination of the financing and loanable funds mechanisms for balance sheet growth. As in financing

¹⁷Benes and Kumhof (2012) also use a financing model.

models, banks issue book money (“fake receipts”) through risky lending. But as in loanable funds 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. Furthermore, the loanable funds dimension of this model could be removed entirely by assuming either risk-free uncollateralized loans, contingent commodities collateral without physical warehousing, or other forms of collateral such as real estate. In Piazzesi and Schneider (2018), bank deposits are created through non-banks’ physical saving and the purchase of Lucas trees by banks from non-banks. But non-banks can also obtain liquidity through intraday loans, which are close relatives of the fake receipts of Donaldson et al. (2018). In the three-period two-state model of Bigio and Weill (2016) 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 resources, and workers still buy the output of producers by paying in physical resources. This dimension of the model could however be removed by allowing for a mechanism similar to that in financing models, whereby workers spend their deposits to buy output from producers, and producers use these deposits to repurchase the illiquid assets.

2.2. Income, Credit and Purchasing Power

In typical loanable funds models purchasing power is, at the aggregate level, equal to prior physical income. Lending does not significantly relax this constraint in aggregate, because it merely transfers physical resources from lenders to borrowers, so that at the time of the loan any increase in the purchasing power of borrowers is offset by a corresponding reduction in the purchasing power of their lenders. By contrast, in financing models aggregate purchasing power equals prior 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 in ledgers rather than physically, through an equal increase in the assets and the liabilities of the banking sector. In turn this new purchasing power, by mobilizing resources that would otherwise have remained idle, trigger’s increases in the economy’s post-loan income, while ex-post spending must of course equal ex-post income. What is needed in this from third parties is not a deposit of physical resources but the acceptance of the new purchasing power in payment for physical resources. This is never in question as long as bank deposits remain the universally accepted medium of exchange. 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 emphasizes 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.¹⁸

¹⁸Bhattacharya 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 at the ZLBD a further reduction in the nominal policy rate reduces output. The reason is that it reduces bank lending rates and thereby credit spreads, which in turn reduces loan extension and deposit creation, in an environment where 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 reducing the net interest margin on new loans. Below a “reversal interest rate”, which does not need to be located at zero, the latter effect starts to dominate, so that accommodative monetary policy becomes contractionary. The reversal interest rate is determined by the pattern of interest semi-elasticities of loan and deposit demands and the quantities of legacy assets and pre-endowed banking equity on the balance sheet. Our model is simpler and has a different transmission mechanism, the rationing of money creation when deposit interest rates are at their exogenous lower bound. 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 is concerned with 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 in Eggertsson et al. (2017) deposits are accumulated through physical saving and do not play a role in economic exchange. The transmission mechanism from lower policy rates to the real economy is therefore different.

The empirical literature documents the effects of long periods at the ZLBD on banks’ profits, equity and lending in many countries around the world. Landier et al. (2013) focus on the US case, and show that an increase in the Fed funds rate near the ZLBD 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) study 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 Mariathasan (2018) study 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. Borio et al. (2015), in a sample of 109 large international banks headquartered in 14 advanced economies from 1995 to 2012, find similar results, and moreover find that this effect is stronger when the interest rate level is lower. 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 in this paper, namely that absent additional policy measures further reductions in policy rates might not be fully transmitted to the real economy, with perverse effects on lending, because of an erosion in banks' intermediation margins near the ZLBD (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.

2.4. Flattening of the Phillips Curve

After the Global Financial Crisis of 2008, output in many countries remained far below the pre-recession trend, unemployment remained high and inflation did not fall by as much as anticipated. In other words, there was a post-crisis flattening of the Phillips curve. Figure 1 shows the US data. A large literature has studied the reasons, but it has not yet converged on a consensus.

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 emphasizes 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).

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 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 ZLBD 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 characterized by high credit spreads, whereas our argument is mainly concerned with the post-crisis ZLBD period, which was characterized by much lower spreads.

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

In this section we provide an estimate of the semi-elasticity of credit supply with respect to the credit spread, a key input into our model calibration and simulation. We collect quarterly US data for the sample period 1997Q1 - 2017Q1 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).¹⁹ 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), of banks' liquid to total assets ratio (*liquidity*), and of the percentage of banks reporting tightening lending standards to large and medium firms (*supply*).

Table 2 reports estimation results for the instrument $DEMAND_{t-4}$.²⁰ The interpretation of the coefficient on the credit 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. This is not a surprisingly large value, given that a 1 percentage point change in the spread is very large compared to historically observed average spreads. 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 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 Global Financial Crisis 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

¹⁹FISIM 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.

²⁰Estimation 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.

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 ZLBD 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 ZLBD less binding over the longer run. However, it is a clear feature of the data that this process takes time, so that the assumption of a fixed credit 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 ZLBD.

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 purely intratemporal, 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 summarizes the timeline, and Figure 4 shows the intra-period flows of deposit payments between agents. Each period begins with the realization of aggregate shocks. Immediately after this banks make loans to firms that create deposits for firms, with nominal interest rates i_t^l and i_t^d , and with both loans and deposits assumed to be non-defaultable. 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. At the microeconomic level, individual banks and the central bank are assumed to participate in a market for central bank reserves, which banks must use to settle payments imbalances among themselves. For simplicity reserves are assumed to be kept in the form of government bonds, and therefore pay the policy rate i_t .²¹ 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 dividends²² to households and for net interest to banks, where it is assumed that banks immediately pass those payments through to households as lump-sum dividends.²³ 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

²¹We also make the simplifying assumption that there is no difference between the interest rates on central bank reserve deposits and reserve loans.

²²It could alternatively be assumed that dividends 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.

²³These dividends represent a conversion of bank equity (earned through the interest rate spread) into bank deposits that are then transferred to households.

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).²⁴ 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.

We note that for agents that do not have access to credit but only to the payment system (households and government in our model), their principal deposits-in-advance constraints are formally equivalent to budget constraints, which state, in terms of physical resources, that expenditure has to be less than or equal to prior income.²⁵ Specifically, the equivalence is between the requirements of having sufficient deposits and sufficient physical income to pay for planned expenditure, so that for such agents, once they have made their decisions affecting income, deposits are not an independent choice variable. But in practice it is always the availability of purchasing power (deposits) that matters for expenditure, and furthermore in modern economies all sectors have some access to credit, and are therefore subject to deposits-in-advance constraints that are not equivalent to budget constraints, as is the case for firms in our model. This explains why we refer even to the constraints of households and government as deposits-in-advance constraints. Of course the problems of these sectors could be generalized, but this would come at the cost of a less transparent model.

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 $D_t(j)$ that pays an interest rate i_t^d , subject to an increasing and convex marginal cost of creating deposits through loans $C(D_t(j))$.²⁶ We interpret this cost as a combination of time and effort spent in the processing of loan applications and regulatory costs that are increasing in the size of banks' balance sheets. Deposit creation is performed exclusively for firms and exclusively at the beginning of each period.

The balance sheet identity for an individual bank is $L_t(j) = D_t(j) + S_t(j)$, where $S_t(j)$ represents the net short position in the reserves market. Bank profits $\Pi_t^b(j)$ consist of three elements, the interest rate spread between loans and deposits $(i_t^\ell - i_t^d) D_t(j)$ that applies to the portion of loans funded by deposits, the cost of making loans to create deposits $C(D_t(j))$, and the interest rate spread between loans and reserves $(i_t^\ell - i_t) S_t(j)$ that applies to the portion of loans funded by reserves after going short in that market. The profit maximization problem is

$$\underset{D_t(j), S_t(j)}{Max} \Pi_t^b(j) = (i_t^\ell - i_t^d) D_t(j) - C(D_t(j)) + (i_t^\ell - i_t) S_t(j). \quad (3)$$

The first order condition for reserves is given by²⁷

$$i_t^\ell = i_t. \quad (4)$$

²⁴In 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.

²⁵Recall that for agents with access to credit, expenditure is less than or equal to prior income plus net new credit.

²⁶For another use of an exogenous intermediation cost function see Eggertsson et al. (2017).

²⁷In the data actual lending rates are of course higher than the policy rate due to risk-based markups.

Banks are assumed to be identical, and therefore make identical loans to firms, both in terms of quantity ($L_t(j) = L_t \forall j$) and pricing. Their customers are assumed to spread their deposit balances evenly across banks ($(D_t(j) = D_t \forall j)$), 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. With these assumptions, all banks have identical balance sheets at all times, with loans equalling deposits ($L_t(j) = D_t(j) \forall j$) and zero positions in the market for reserves ($(S_t(j) = 0 \forall j)$). The implication of (4) is therefore that if an individual bank deviated from this symmetric equilibrium by lending an additional unit of currency, it would lose all newly created deposits to other banks given the assumption that depositors spread their balances and that each bank is infinitesimally small, and it would make zero profits on the resulting short position, thereby eliminating its incentive to do so.

The cost of making loans to create deposits $C(D_t(j))$ is assumed to be increasing at an increasing rate in the quantity of deposits and therefore, given the foregoing results, in the size of banks' balance sheet:²⁸

$$C(D_t(j)) = \frac{\kappa}{1 + \frac{1}{\xi}} P_t \bar{a} \left(\frac{D_t(j)}{P_t \bar{a}} \right)^{1 + \frac{1}{\xi}}. \quad (5)$$

Here \bar{a} is calibrated to equal the steady state real size of banks' balance sheet, and ξ determines the spread semi-elasticity of credit supply. For simplicity we assume that $C(D_t(j))$ represents a lump-sum transfer to households rather than a resource cost. Because banks also transfer their profits to households, total lump-sum receipts of households from bank j equal $(i_t^\ell - i_t^d) D_t(j) = (i_t - i_t^d) L_t(j)$. Because of symmetry across banks the index j can now be dropped. Then the deposits optimality condition, in real terms, is given by

$$d_t = \ell_t = \bar{a} \left(\frac{i_t - i_t^d}{\kappa} \right)^\xi, \quad (6)$$

The equality $d_t = \ell_t$ states that in our economy money equals loans, or credit. Furthermore, we have $i_t^d = 1$ at the ZLBD. Condition (6) shows that in the unconstrained economy 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 in the ZLBD-constrained economy credit supply responds highly inelastically to credit demand, as credit must adjust so that the bank can continue to make zero profits at the margin, given that i_t is exogenous to the bank and i_t^d cannot adjust. The parameter ξ plays a critical role for the quantity of credit at the ZLBD, while it mainly determines the evolution of deposit interest rates away from the ZLBD. The equation (6) can be used to compute the spread semi-elasticity of credit supply with respect to the credit spread, $d \ln(\ell_t / \bar{\ell}) / d \hat{i}_t$, 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 credit supply increases by 10 percent for a 1 percentage point increase in the spread.

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

²⁸For another use of an exogenous intermediation cost function see Eggertsson et al. (2017). For the purpose of studying the effects of monetary policy this formulation has the advantage of keeping the model's transmission mechanism simple and transparent. In future work on macroprudential policy, which unlike monetary policy may itself affect the shape of the cost function, we will aim to replace this with a more comprehensive model of bank optimization.

necessarily arbitrary. For simplicity and ease of interpretation, we assume that all deposit interest is received by firms. This ensures that the spread between loan and deposit rates 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. Firms pay this spread to rent the exclusive ability of banks to create a generally accepted medium of exchange.

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 price 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

$$G_{P,t}(j) = \frac{\phi_p}{2} y_t \left(\frac{\frac{P_t(j)}{P_{t-1}(j)}}{\pi_{t-1}} - 1 \right)^2, \quad (7)$$

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^ℓ on the loans while earning a gross nominal interest rate of i_t^d on the corresponding deposits. Using the equality $D_t(j) = L_t(j)$, the nominal profit of firm j is therefore given by

$$\Pi_t^F(j) = P_t(j)y_t(j) - W_t h_t(j) - R_t^k K_t(j) - L_t(j)(i_t^\ell - i_t^d) - P_t G_{P,t}(j). \quad (8)$$

The deposits-in-advance constraint of firm j states that it needs to use its deposits 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. We therefore have

$$L_t(j) \geq L_t(j)(i_t^\ell - i_t^d) + W_t h_t(j) + R_t^k K_t(j) + \Pi_t^F(j). \quad (9)$$

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 $D_t^{hb}(j) = L_t(j)(i_t^\ell - i_t^d)$ (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 $i_t^\ell - i_t^d$, must be positive in equilibrium by (6), (4) and the Inada conditions on consumption utility - recall that no production, and therefore no consumption, could take place in the complete absence of monetary exchange. For the remainder of this paper we will inquire for each agent whether prior income or net new credit finances spending. The key observation for the case of firms is that before starting production firms' prior income equals zero, and it is *only* the extension of new credit that allows the production cycle to start.

Combining (8) and (9), we obtain the final form of the deposits-in-advance constraint:

$$L_t(j) \geq P_t(j)y_t(j) - P_t G_{P,t}(j) . \quad (10)$$

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

$$y_t^s(j) = S_t^\alpha h_t(j)^{1-\alpha} K_t(j)^\alpha , \quad (11)$$

where α calibrates the capital share in output and S_t^α is a first-order autoregressive process for total factor productivity. Standard optimization 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 optimization problem of firms is

$$\begin{aligned} \underset{\{P_t(j), h_t(j), K_t(j), L_t(j)\}_{t=0}^{\infty}}{Max} \quad & E_0 \sum_{t=0}^{\infty} \beta^t \Lambda_t^h \left[(P_t(j))^{1-\theta} (P_t)^\theta y_t - W_t h_t(j) - R_t^k K_t(j) - L_t(j)(i_t^\ell - i_t^d) \right. \\ & - \frac{\phi_P}{2} P_t y_t \left(\frac{P_t(j)}{P_{t-1}(j)} - 1 \right)^2 - MC_t \left((P_t(j))^{-\theta} (P_t)^\theta y_t - S_t^\alpha h_t(j)^{1-\alpha} K_t(j)^\alpha \right) \\ & + \eta_t^f \left(L_t(j) - (P_t(j))^{1-\theta} (P_t)^\theta y_t + \frac{\phi_P}{2} P_t y_t \left(\frac{P_t(j)}{P_{t-1}(j)} - 1 \right)^2 \right) \\ & \left. - \eta_t^b \left(L_t(j) - P_t \bar{a} \left(\frac{i_t^\ell - i_t^d}{\kappa} \right)^\xi \right) \right] , \end{aligned} \quad (12)$$

where $i_t^d = 1$ at the ZLBD, 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 maximizes the present discounted value of its profits subject to three constraints. First, goods supply must equal goods demand, with a multiplier on this constraint of MC_t , which denotes nominal marginal cost. Second, the deposits-in-advance constraint (10) must hold, with a multiplier of η_t^f . Third, banks' participation constraint (6), or credit rationing constraint, must hold, with a multiplier of $\eta_t^b \geq 0$, where changes in η_t^b depend on relative changes in credit supply and credit demand. In the unconstrained economy the interest rate i_t^d is free to vary to achieve the spread that is necessary for the bank to elastically accommodate credit demand. Therefore, there is no quantity rationing of credit and $\eta_t^b = 0$.

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

$$\frac{\mu mc_t}{(1 - \eta_t^f)} - 1 = \phi_p (\mu - 1) \left(\frac{\pi_t}{\pi_{t-1}} - 1 \right) \frac{\pi_t}{\pi_{t-1}} - \beta E_t \frac{\lambda_{t+1}^h}{\lambda_t^h} \frac{y_{t+1}}{y_t} \frac{(1 - \eta_{t+1}^f)}{(1 - \eta_t^f)} \phi_p (\mu - 1) \left(\frac{\pi_{t+1}}{\pi_t} - 1 \right) \frac{\pi_{t+1}}{\pi_t} = 0 , \quad (13)$$

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

$$i_t^\ell - i_t^d = \eta_t^f - \eta_t^b . \quad (14)$$

In the unconstrained economy this simplifies to $1 - \eta_t^f = 1 - i_t^\ell + i_t^d$, so that the Phillips curve is directly affected only by the credit spread. In the ZLBD-constrained economy we have $1 - \eta_t^f =$

$2 - i_t^\ell - \eta_t^b$, in other words the multiplier on the credit rationing constraint directly enters the Phillips curve, with higher η_t^b putting upward pressure on prices. We calibrate our ZLBD-constrained model economy such that steady state interest rates are far from the point where the economy would escape the ZLBD, and we assume that the standard errors of shocks are small enough so that the possibility of transitioning between ZLBD-constrained and unconstrained economies can be ignored. This allows us to focus our analysis on the two polar extremes, which illustrate all the key economic insights.

4.4. Households

There is a continuum of households of measure 1, with an individual household indexed by j . Utility depends on consumption $c_t(j)$ and hours worked $h_t(j)$, and is subject to consumption demand shocks S_t^c that follow a first-order autoregressive process. The intertemporal elasticity of substitution is ϵ , external habit persistence is v , the weight on labour disutility is χ , and the labour supply elasticity equals 1. Households maximize lifetime utility, where consumption utility satisfies the Inada conditions, by choosing paths for $c_t(j)$, $h_t(j)$, physical investment $I_t(j)$, physical capital $k_t(j)$ and holdings of government bonds $B_t(j)$,

$$\text{Max}_{\{c_t(j), h_t(j), I_t(j), k_t(j), B_t(j)\}_{t=0}^{\infty}} E_0 \sum_{t=0}^{\infty} \beta^t [S_t^c (1-v)^{\frac{1}{\epsilon}} \frac{(c_t(j) - v c_{t-1})^{1-\frac{1}{\epsilon}}}{1 - \frac{1}{\epsilon}} - \frac{\chi}{2} h_t(j)^2] \quad , \quad (15)$$

subject to a sequence of deposits-in-advance constraints. Household spending is financed entirely through prior income received in the form of bank deposits, which in this case includes 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 $D_t^{hb}(j)$. Households' first deposits-in-advance constraint is that the above-mentioned incomes must be sufficient to cover gross payments to the government, including purchases of net new government debt and labor income taxes:

$$W_t h_t(j) + R_t^k k_{t-1}(j) + D_t^{hm}(j) + D_t^{hb}(j) \geq B_t(j) - B_{t-1}(j) + W_t h_t(j) \tau_{L,t} \quad . \quad (16)$$

In our simulations this constraint is never binding. For future reference, we denote the net aggregate deposits collected by the government from households by $D_t^{gh} = B_t - B_{t-1} + W_t h_t \tau_{L,t}$. Next, households receive net interest $i_t - 1$ on government bonds held between periods t and $t + 1$. This interest 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. Households's second deposits-in-advance constraint is that their factor and dividend incomes minus payments to the government net of interest received 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

$$G_{I,t}(j) = \frac{\phi_I}{2} I_t \left(\frac{I_t(j)}{I_{t-1}(j)} - 1 \right)^2 \quad , \quad (17)$$

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

$$W_t h_t(j) + R_t^k k_{t-1}(j) + D_t^{hm}(j) + D_t^{hb}(j) - (B_t(j) - B_{t-1}(j) - W_t h_t(j) \tau_{L,t} - B_t(j)(i_t - 1)) \geq \quad (18)$$

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

This deposits-in-advance constraint must be binding in equilibrium because the opportunity cost to households of investing in idle and (for households) zero interest deposit balances, the net interest rate on government bonds $i_t - 1$, must be positive in equilibrium because, as discussed above, $i_t^\ell - i_t^d$ must be positive in equilibrium. Finally, the accumulation equation for physical capital is given by the law of motion

$$k_t(j) = (1 - \delta) k_{t-1}(j) + I_t(j) , \quad (19)$$

where δ is the depreciation rate of capital. Given the binding deposits-in-advance constraint, the household problem is standard for New Keynesian models. All optimality conditions are therefore also standard, and we do not show them to conserve space.

4.5. Government

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

$$D_t^{gh} \geq B_t (i_t - 1) + P_t g_t . \quad (20)$$

Government spending is financed entirely through prior income received in the form of bank deposits, which in this case includes household income transferred to government in payment of taxes and in exchange for new government bonds. The deposits-in-advance 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 $i_t - 1$, must be positive in equilibrium because $i_t^\ell - i_t^d$ must be positive in equilibrium. The labour tax rate is determined by the fiscal rule

$$\tau_{L,t} - \bar{\tau}_L = f_b \left(\frac{b_t}{4y_t} - \frac{\bar{b}}{4\bar{y}} \right) , \quad (21)$$

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

$$i_t = ((2 - \beta) \pi_t) \left(\frac{\pi_t}{\bar{\pi}} \right)^{m_\pi} \left(\frac{\ell_t}{\bar{\ell}} \right)^{m_\ell} , \quad (22)$$

where m_π is the inflation gap feedback coefficient and m_ℓ is the loans gap feedback coefficient. 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

$$y_t = c_t + I_t + g_t + G_{p,t} + G_{I,t} . \quad (23)$$

The market clearing condition for physical capital is

$$K_t = k_{t-1} . \quad (24)$$

And finally, GDP is defined as

$$gdp_t = c_t + I_t + g_t . \quad (25)$$

4.7. Calibration

Table 3 presents the details of our model calibration. It distinguishes between calibrated parameter values in a ZLBD-constrained (fourth column) and an unconstrained (fifth column) economy. The discount factor β is set to fix the steady state real policy interest rate to 3% per annum in both models. The nominal and real rates are equal in steady state because the central bank’s net inflation target is set to 0% per annum. Keeping the steady state policy rate equal across models has the advantage of implying similar steady state real variables as we move from unconstrained to ZLBD-constrained economies.²⁹ Instead of differences in the steady state policy rate, distinctions between unconstrained and ZLBD-constrained economies are therefore assumed to be due to differences in steady state deposit interest rates that are in turn due to differences in the cost of supplying credit. To implement this we specify three models that differ by the value taken by the deposit rate, an unconstrained model with a rate of 1% per annum, a hypothetical unconstrained model with a -1% rate, and a ZLBD-constrained model with a 0% rate. The first and second models are used to calibrate the respective parameters of the credit supply cost function (5), \bar{a} , κ and ξ . The three parameters from the second (hypothetical) model are then applied to the third, ZLBD-constrained, model. The idea is that a “fundamental” credit supply cost function can be identified from the unconstrained model under the counterfactual (in the model) assumption that deposit rates can become negative, and that the ZLBD does not affect this function but instead forces the economy’s steady state, and especially banks’ lending volume, to adjust to the constraint, given the credit supply cost function of the hypothetical unconstrained economy. In both unconstrained economies the elasticity parameters ξ are set to fix the steady state spread semi-elasticity of credit 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{a} are determined by loan demand at that interest rate.

The remainder of the calibration applies equally to both models. For preferences, we remain close to much of the macro literature by setting households’ intertemporal elasticity of substitution to $\epsilon = 0.5$ and the habit persistence parameter to $v = 0.75$. The weight χ on hours in the utility function is set to normalize 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%. Again, both are close to recent US data. 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 inflation stickiness to $\phi_p = 200$. Together these values imply a contract duration of 5 quarters in an equivalent Calvo (1983) model with indexation to past inflation. 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 these coefficients. The persistence of first-order autoregressive shocks in our illustrative simulations is $\rho_c = 0.7$ for consumption demand shocks (habit persistence imparts additional persistence to this shock) and $\rho_a = 0.95$ for technology shocks. With the foregoing calibration our ZLBD-constrained model economy is located well within the ZLBD-constrained region in steady state, and it remains in that region even after shocks that have sizeable real and

²⁹Otherwise there would for example be very large differences in steady state capital stocks.

financial effects. This justifies our reliance on simulations that ignore the small probability of transitioning to the unconstrained economy (and vice versa).

5. Model Simulations

In this section we discuss impulse responses that first illustrate the behavior of the ZLBD-constrained economy as a function of the spread semi-elasticity of credit supply, and that then compare the behavior of the ZLBD-constrained economy to that of the unconstrained economy. In each case the black solid, dark blue dashed and red dotted lines show simulations for the ZLBD-constrained economy with spread semi-elasticities of 10/5/1, while the green dashed and dotted lines show simulations for the unconstrained economy with spread semi-elasticities of 10/5. We consider it important to conduct sensitivity analysis with respect to the spread semi-elasticity because, while our own estimate of around 10 is statistically significant and robust to the use of alternative instruments, at this point this is the model parameter for which there is the least guidance from other literature.

The first subsection illustrates the behavior of the ZLBD-constrained economy under standard demand and supply shocks when the monetary authority follows an interest rate rule that satisfies the Taylor principle $m_\pi > 0$. It is well known that away from the ZLBD such rules stabilize inflation and output. We show that at the ZLBD the same type of rule is contractionary under shocks that reduce the rate of inflation, such as negative shocks to consumption demand and positive shocks to technology. We also show that at the ZLBD the Phillips curve is flatter than in the equivalent unconstrained economy.

The second subsection illustrates the behavior of the ZLBD-constrained economy when the monetary authority modifies its policy rule to deal with this problem. The key insight is that at the ZLBD a policy of deliberately increasing inflation and therefore the nominal policy rate increases spreads, lending and output, and this can help the economy to not only deal with negative shocks but also to reach a permanently higher level of economic activity. We therefore first study, for the consumption demand shock analyzed in the first subsection, an endogenous response to a loans gap in addition to the inflation gap, and we then consider an exogenous and permanent increase in the policy rule's inflation target.

5.1. Reductions in the Policy Rate Are Contractionary at the ZLBD

This subsection studies two shocks that have a disinflationary effect. Under our maintained assumption about the monetary policy rule, this triggers a reduction in the nominal policy rate and therefore in credit spreads. We show that this response reduces output in a ZLBD-constrained economy unless the spread semi-elasticity of credit supply is extremely low. The reason is that even for moderately low semi-elasticities the effect of lower nominal policy rates on spreads and the quantity of credit dominates the effect of lower real interest rates on aggregate demand through intertemporal substitution.

5.1.1. Consumption Demand Shock

The top half of Figure 5 shows the simulated effects of a shock to consumption preferences S_t^c whereby consumption in the ZLBD-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 credit spread and thereby the supply of credit. When credit supply is even moderately elastic (i.e. even for an elasticity as low as 1) with respect to the credit spread, the decrease in the supply of credit is larger, thereby reducing output beyond the direct effect of the shock, and increasing the credit rationing multiplier and thus, *ceteris paribus*, marginal cost and inflation. The more elastic is credit, the larger is the decrease in output and the smaller the decrease in inflation.

For the baseline simulation with a spread semi-elasticity of 10, investment comoves with consumption because the shortage of deposit money constrains purchases of both. As credit supply becomes less elastic, the reduction in credit supply decreases but so does the reduction in credit demand. 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. Quantitatively, with successive drops in the elasticity of credit supply, reductions in credit supply decrease by more than reductions in credit demand. However, it can be shown that the spread semi-elasticity of credit supply needs to become even smaller than in Figure 5, specifically that it needs to drop below 0.5, for the credit rationing multiplier to drop on impact. However, before this happens the reduction in credit supply becomes sufficiently small to cause investment to rise instead of falling (see the red dotted line). In other words, the positive comovement between consumption and investment depends on the spread semi-elasticity of credit supply being sufficiently high, but with values even well below our baseline estimate leading to very strong comovement.

The bottom half of Figure 5 shows the same shock as the top half. It compares the ZLBD-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 of the two economies are similar, but otherwise the results are strikingly different.

For the unconstrained economy the effect of the credit rationing 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 larger drop in the nominal and real policy rate. Because this is accompanied by a similar drop in the deposit rate, the effect on the credit spread is smaller than in the ZLBD-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 than in the ZLBD-constrained economy, and a strong increase rather than a decrease in investment. This model does therefore not generate comovement between consumption and investment under shocks to aggregate demand.

For the ZLBD-constrained economy, credit rationing that follows a contractionary demand shock implies a larger output contraction accompanied by a more subdued inflation response. In other words, the Phillips curve of the ZLBD-constrained economy is flatter than that of the unconstrained economy.

5.1.2. Technology Shock

The top half of Figure 6 shows the simulated effects of a persistent shock to technology S_t^a whereby total factor productivity increases by 1.0% on impact. In the ZLBD-constrained economy this otherwise expansionary shock leads to a drop in output of almost 0.6% after 6 quarters. The reason is that an expansionary technology shock reduces inflation and therefore, due to the monetary policy rule, the policy rate, the credit spread and deposits. Credit rationing therefore leads to a drop in output and a dampened effect on inflation. With less elastic credit supply we observe less credit rationing, more stable output and a larger drop in inflation. For high and moderate spread semi-elasticities of credit supply consumption and investment again comove.

The bottom half of Figure 5 shows that in the unconstrained economy the favorable 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 credit spread to rise and giving banks an incentive to supply the additional credit and money that is needed by an economy that attempts to realize the potential of improved technology.

As for the Phillips curve, given the increase in potential output following the technology shock, and given rigidities in the adjustment of the components of aggregate demand, the output gap drops together with inflation. However, in the ZLBD-constrained economy the drop in the output gap is much larger while the drop in inflation is much smaller. In other words, the Phillips curve is flatter.

5.2. Inflationary Policies Are Expansionary at the ZLBD

This subsection studies two policies that have an inflationary effect, and that therefore trigger an increase in the nominal policy rate, the credit spread, deposits and output. In the ZLBD-constrained economy temporary inflationary policies have a much greater expansionary effect than in an unconstrained economy because they reduce the severity of credit rationing. And permanent inflationary policies, which have no real effect in an unconstrained economy, have a very strong and permanent effect on output.

5.2.1. Monetary Policy Rule with a Loans Gap

The simulations in Figures 5 and 6 emphasize that at the ZLBD systematic reductions in the nominal policy rate in response to disinflationary shocks are contractionary. This raises two questions: First, would a weaker systematic response to inflation mitigate the contractionary effects of disinflationary shocks? And second, could a systematic response to other gap variables stabilize output

more effectively? Figure 7 shows that the answer to the first question is no while the answer to the second question is yes.

The top half of Figure 7 studies the same contractionary shock to consumption demand as in Figure 5, in the ZLBD-constrained economy and with a spread semi-elasticity of credit 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 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 credit spread and credit. The smaller decline in the real policy rate in turn implies a larger initial decline in investment and output. This does not support a policy of responding less strongly to inflation.

The bottom half of Figure 7 again studies the same shock, but in this case it 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 credit spreads, this *ceteris paribus* triggers a systematic (rules-based) monetary easing, thereby generating an inflationary response. Therefore, the policy rate, and consequently credit spreads and deposits, 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 higher credit and lower real interest rates implies a shallower contraction, specifically a smaller drop in consumption and an increase rather than a drop in investment. At the ZLBD a monetary policy response to the loans gap therefore becomes a useful countercyclical tool.

Figure 8 studies the determinacy properties of the monetary policy rule (22) 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 $m_\pi > 0$ 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 an increase in loans, by (6), implies an increase in the credit spread and therefore 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 when deposit rates can adjust. For the same reason, with a strong inflation feedback at $m_\pi = 3$ any loans gap feedback is compatible with determinacy.

For the ZLBD-constrained economy in the top half of Figure 9, 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.

5.2.2. Permanent Increase in the Inflation Target

Because a ZLBD-constrained economy operates permanently below capacity because of credit rationing, additional credit can increase the economy's output. This suggests that a permanent increase in the policy rate, in order to permanently increase banks' lending margins, would be beneficial. This is the subject of our final simulation in Figure 9, which studies the effects of an unanticipated and permanent 0.25 percentage point increase in the nominal policy rate for a given equilibrium real interest rate, through an unanticipated and permanent increase in the inflation tar-

get in the monetary policy rule.³⁰ The figure shows the effects under credit 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 different credit spreads.

As shown in the top half of Figure 9, the effect in the ZLBD-constrained economy is to immediately stimulate an increase in inflation. This leads to permanent increases in the nominal policy rate and the credit spread, and therefore supports a permanent increase in deposits 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 a semi-elasticity of 1. This in turn permits a similar permanent increase in output.

As shown in the bottom half of Figure 9, the effect of this policy in the unconstrained economy is very small. The real policy rate drops by 45 basis points on impact, but this drop is extremely short-lived, while the credit spread remains unchanged due to adjustments in the deposit rate. As a result there is a very short-lived boost to output of less than 0.05%, with no permanent change.

6. Conclusions

We have studied a New Keynesian DSGE model where banks create deposits through loans, subject to increasing marginal costs of lending. Banks provide a payment system that must be used by all spenders to make payments to each other. 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-cum-depositor. Banks are essential for economic activity because deposit payments are a prerequisite for all real economic activity, and because additional deposit creation increases non-banks' aggregate purchasing power beyond their prior income. In other words, non-banks do not face budget constraints, whereby their expenditure has to equal their prior income, but rather deposits-in-advance constraints, whereby their expenditure has to equal their prior income plus net new deposit creation, and where additional deposits can mobilize 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 on deposit interest rates (ZLBD), in an economy where lending interest rates move towards zero with the policy rate and therefore compress credit spreads. We estimate a sizeable semi-elasticity of credit supply with respect to the credit spread from US data. We then calibrate our model with this semi-elasticity, and also with much more moderate semi-elasticities, and find that, once deposit rates have reached the ZLBD, any further drop in the policy rate significantly reduces deposit creation and thereby ultimately output.

Therefore, when interest rate setting at the ZLBD follows a conventional monetary policy reaction function that responds to disinflationary shocks by lowering the policy rate, this has negative effects on output. The policy response can take this into account by countercyclically responding to a loans gap in addition to an inflation gap, or it can move in the direction of escaping from the ZLBD by

³⁰A transitory expansionary shock to the monetary policy rule would have transitory expansionary effects.

permanently increasing the inflation target in order to permanently stimulate deposit creation and output.

We also find that at the ZLBD Phillips curves are flatter when monetary policy continues to respond to inflation in the pre-ZLBD fashion by following a Taylor-type rule. The reason is that, following disinflationary shocks, lower factor cost inflation leads to a reduction in policy rates that now, unlike in the pre-ZLBD economy, leads to credit rationing that both has an offsetting inflationary effect and a sizeable negative effect on output. As a result, the drop in the output gap is much larger while the drop in inflation is much smaller.

Finally, credit rationing at the ZLBD implies a strong positive comovement between consumption and investment, because both are constrained by the availability of sufficient purchasing power.

The model used in this paper has been kept simple to focus on the main 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 ZLBD, but there are many other candidates, including the many new regulations that have been imposed on banks in the wake of the Global Financial Crisis of 2008. We want to use our framework to study these next, after embedding a more detailed model of bank optimization 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 credit 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

(quarterly data, 1997Q1 to 2017Q1)

Table 2. Estimation Results (2SLS)

First-Stage Regression

	Coefficient	t	P> t 	95% Confidence Interval
<i>cispreadnet_t</i>				
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

	Coefficient	t	P> t 	95% Confidence Interval
<i>Lnrealciloan_t</i>				
<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	ZLBD-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 Spread Semi-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: \bar{a}		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

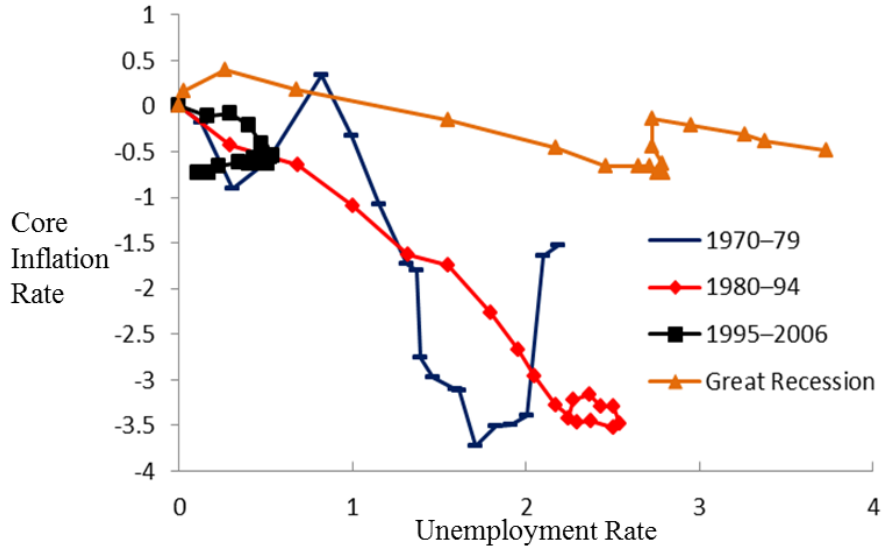


Figure 2: US Commercial and Industrial Loan Spreads

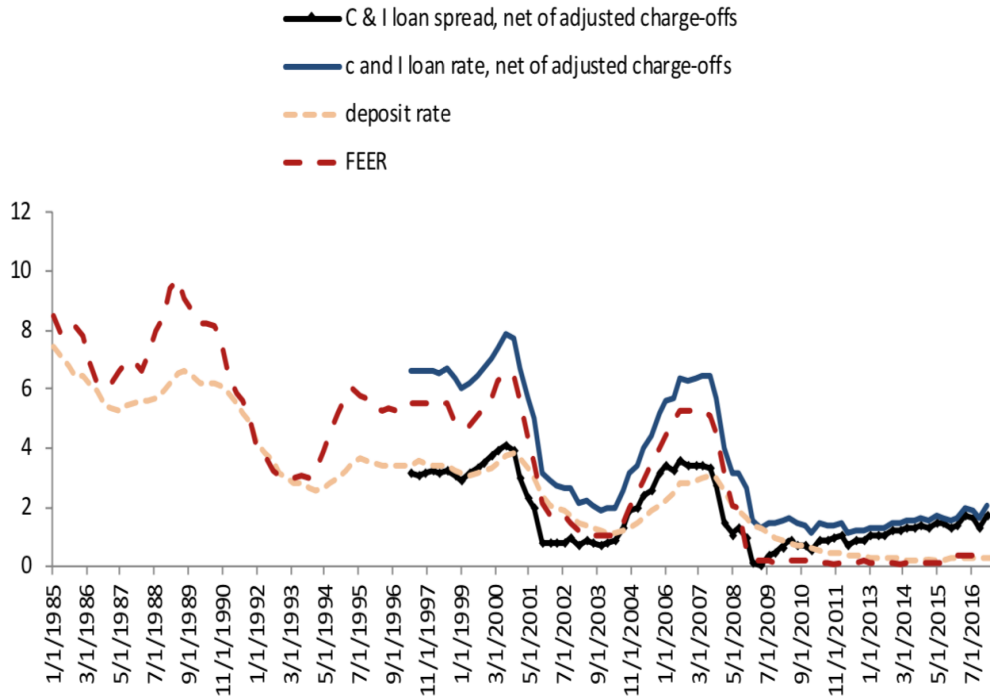


Figure 3: Timeline of Intra-Period Cash Flows

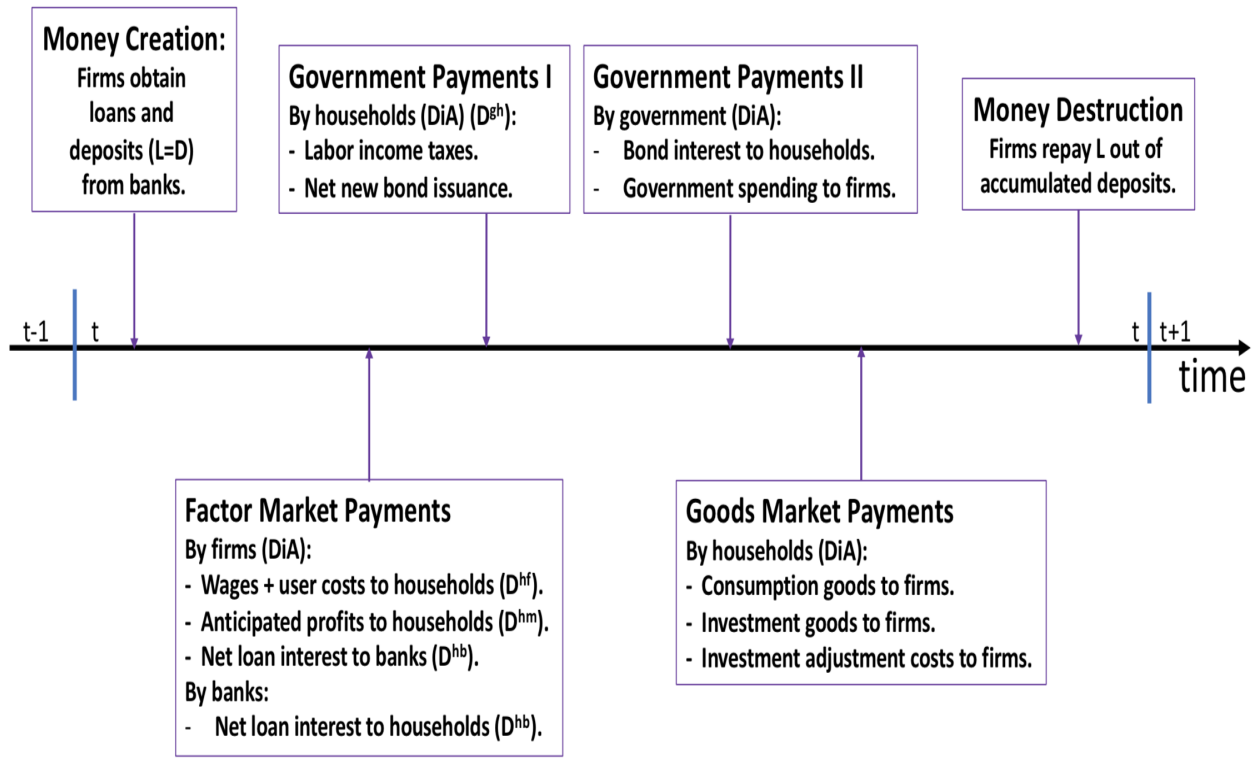


Figure 4: The Payment Cycle

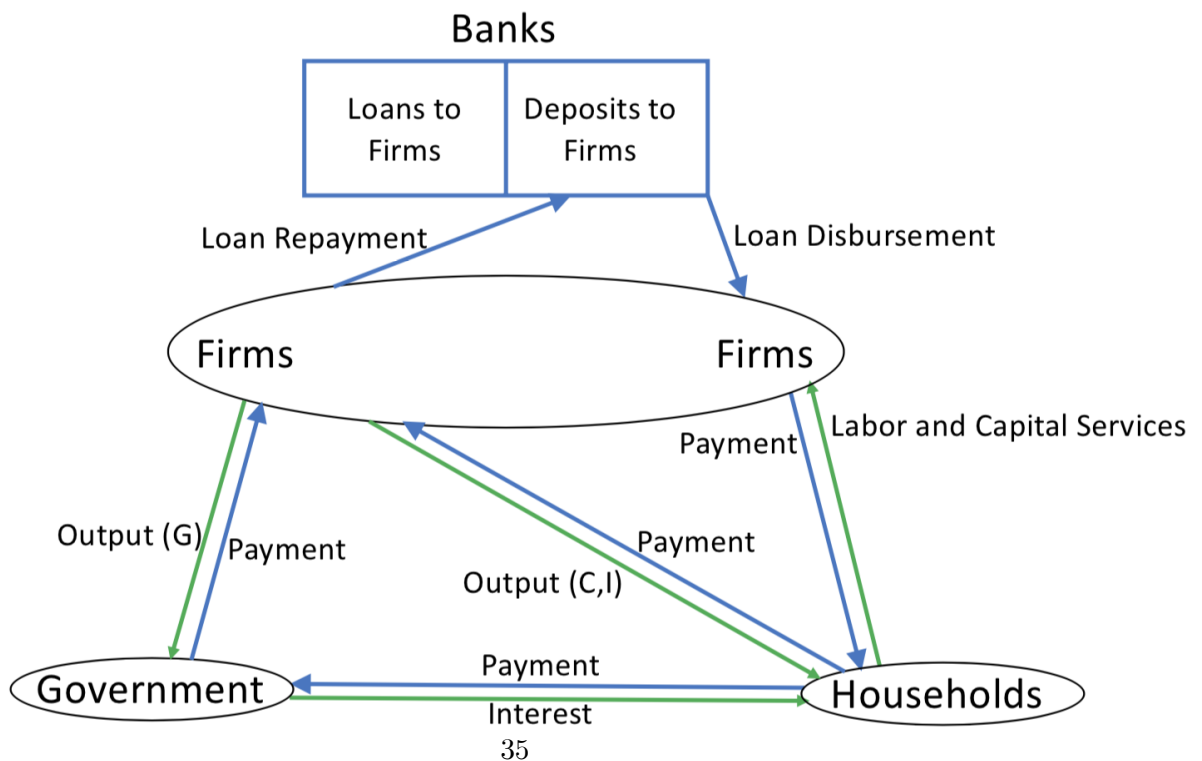
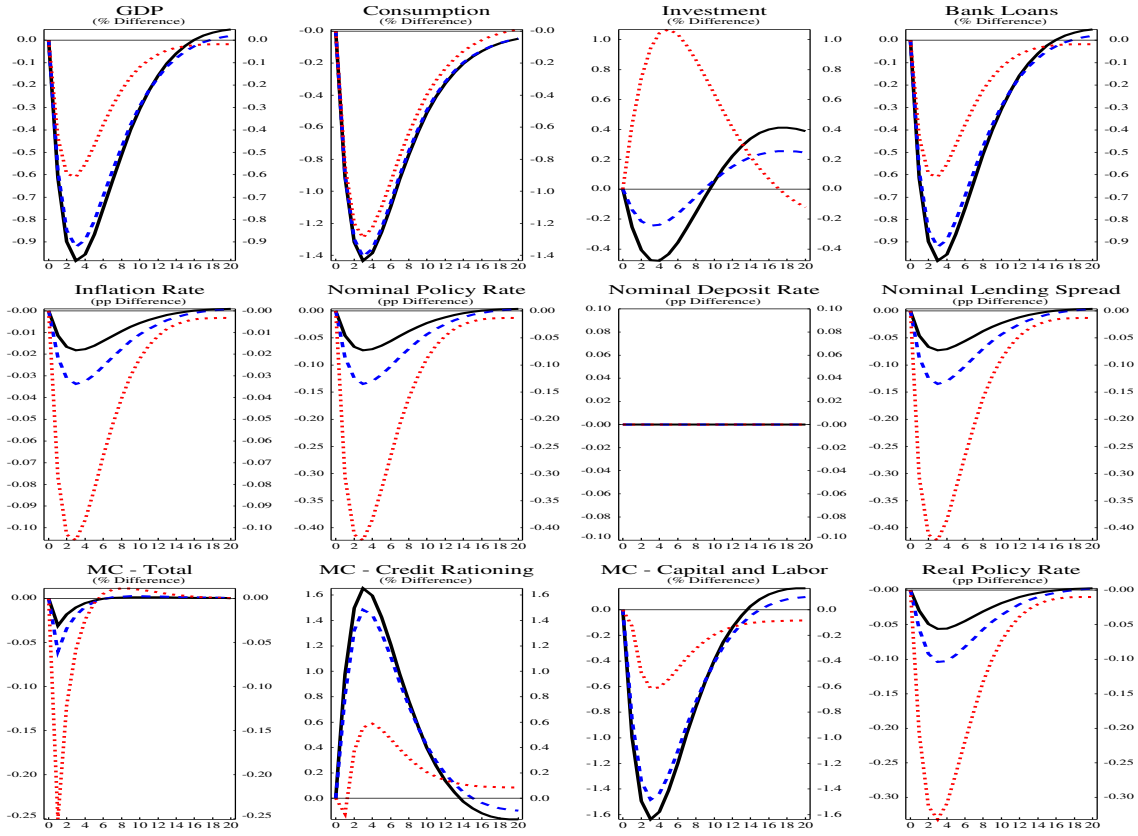
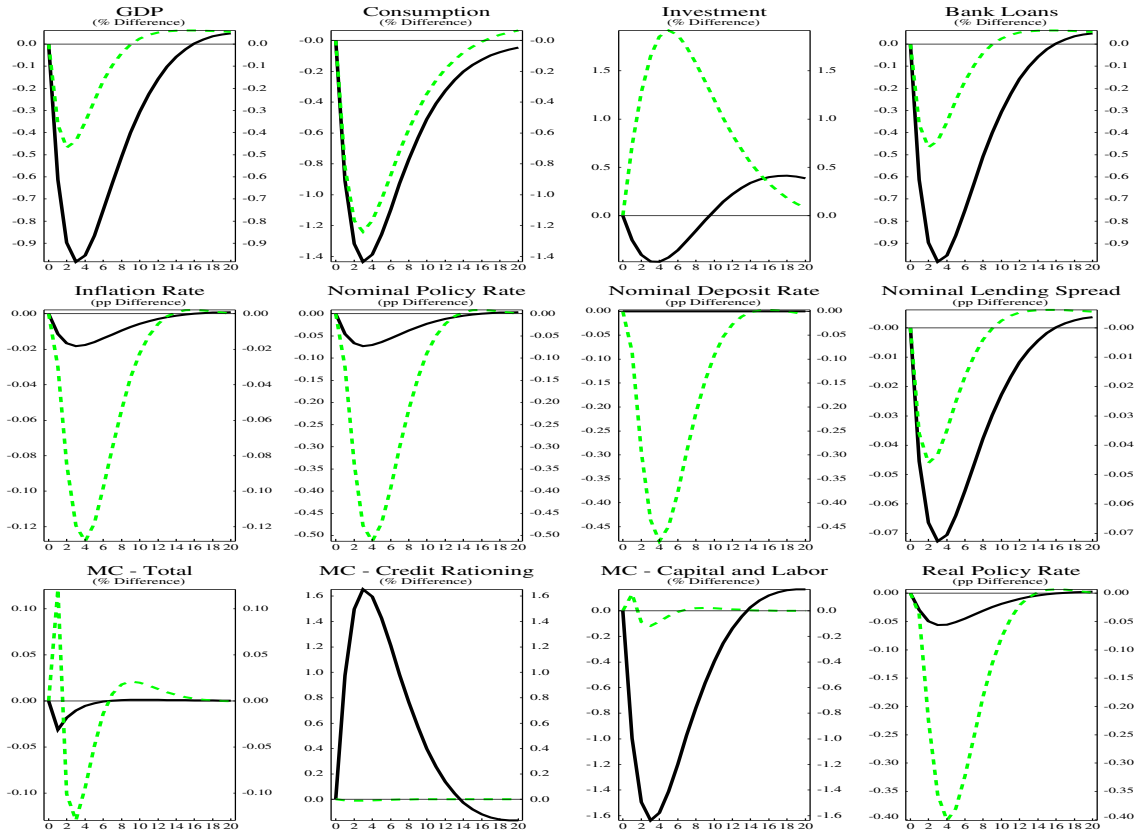


Figure 5: Consumption Demand Shock

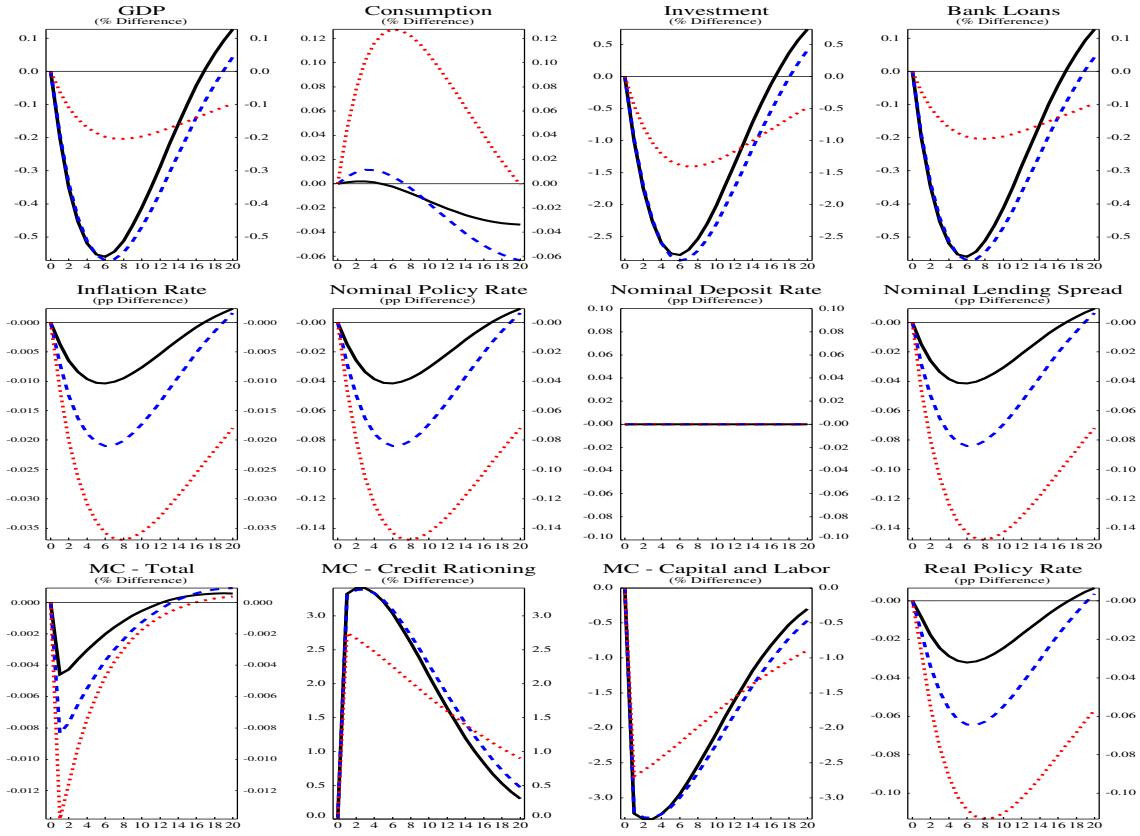


ZLBD-Constrained Economy (spread semi-elasticities: solid = 10 / dashed = 5 / dotted = 1)

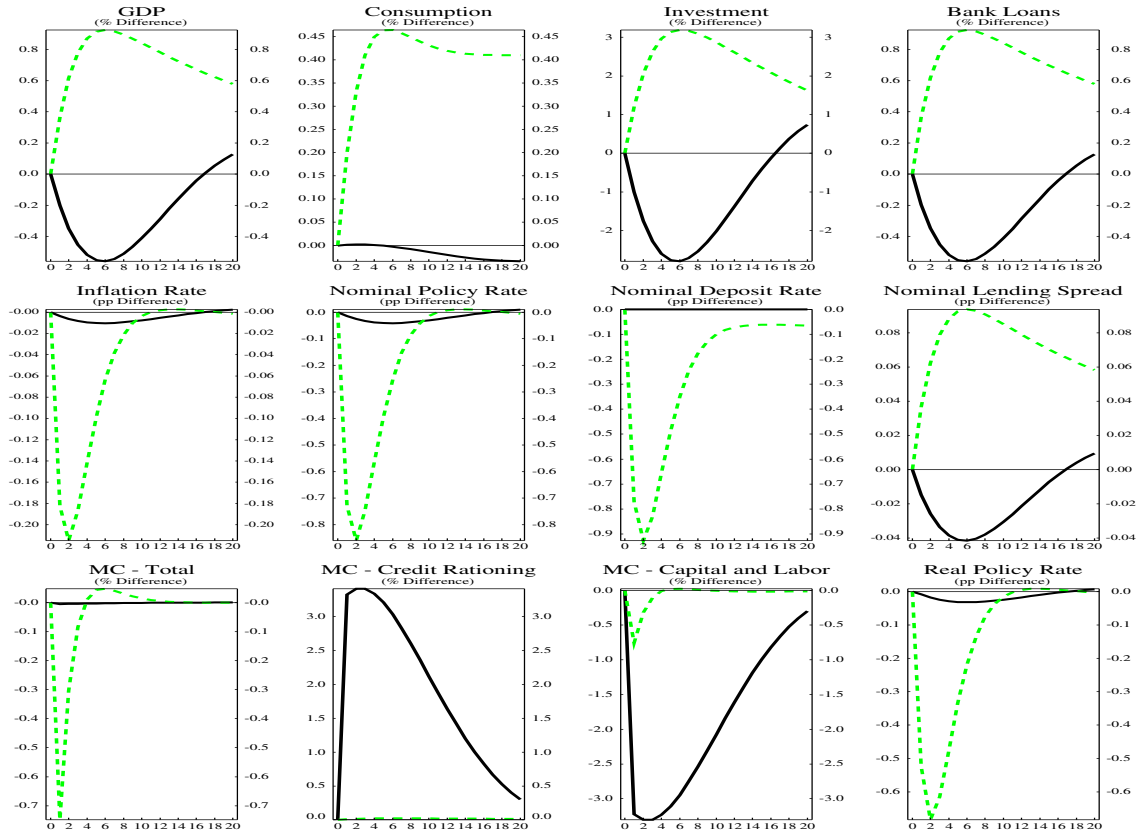


ZLB-Constrained (solid) versus Unconstrained (dashed) Economy (spread semi-elasticity = 10)

Figure 6: Technology Shock

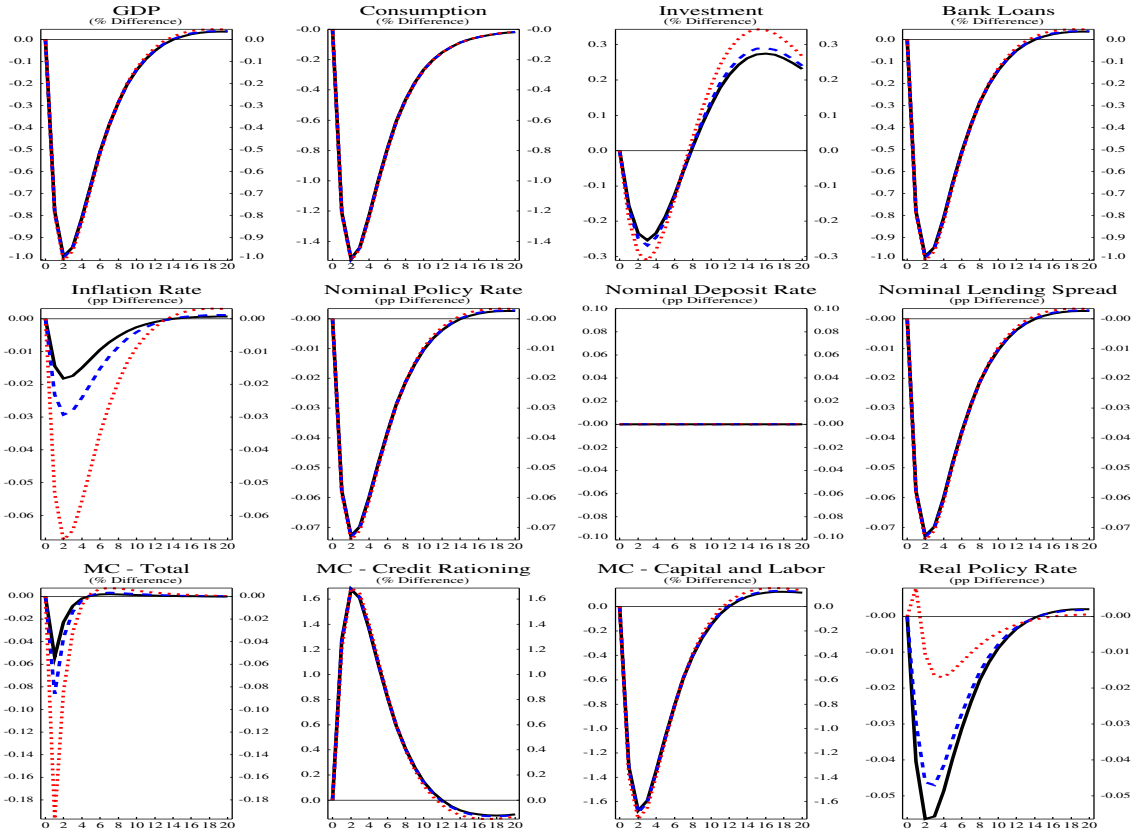


ZLBD-Constrained Economy (spread semi-elasticities: solid = 10 / dashed = 5 / dotted = 1)

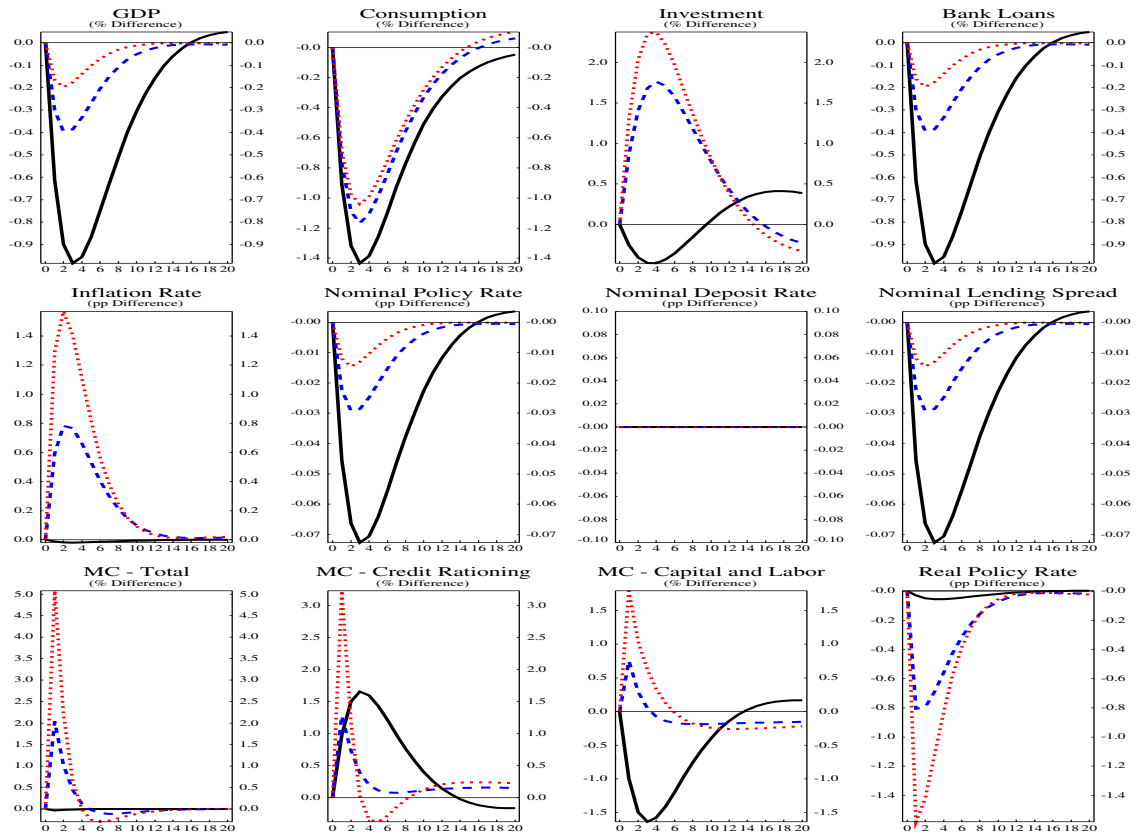


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ZLBD-Constrained (solid) versus Unconstrained (dashed) Economy (spread semi-elasticity = 10)

Figure 7: Consumption Demand Shock with a Loans Gap Rule



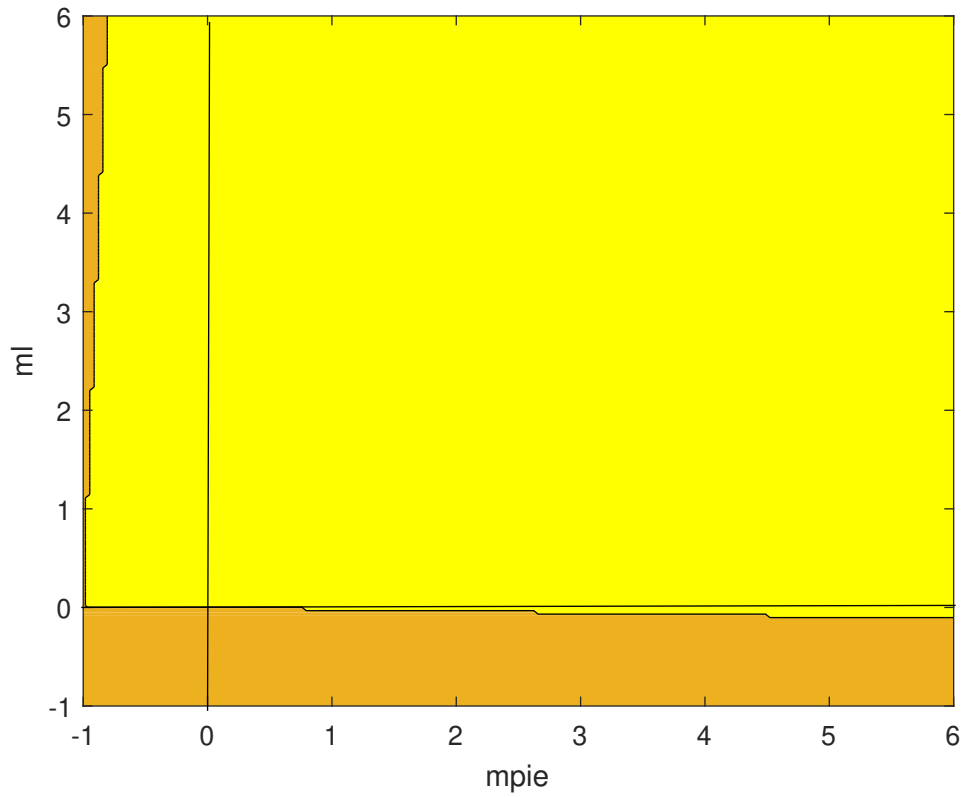
ZLBD-Constrained Economy - Weaker Inflation Response: m_π : solid = 3 / dashed = 1.5 / dotted = 0.1



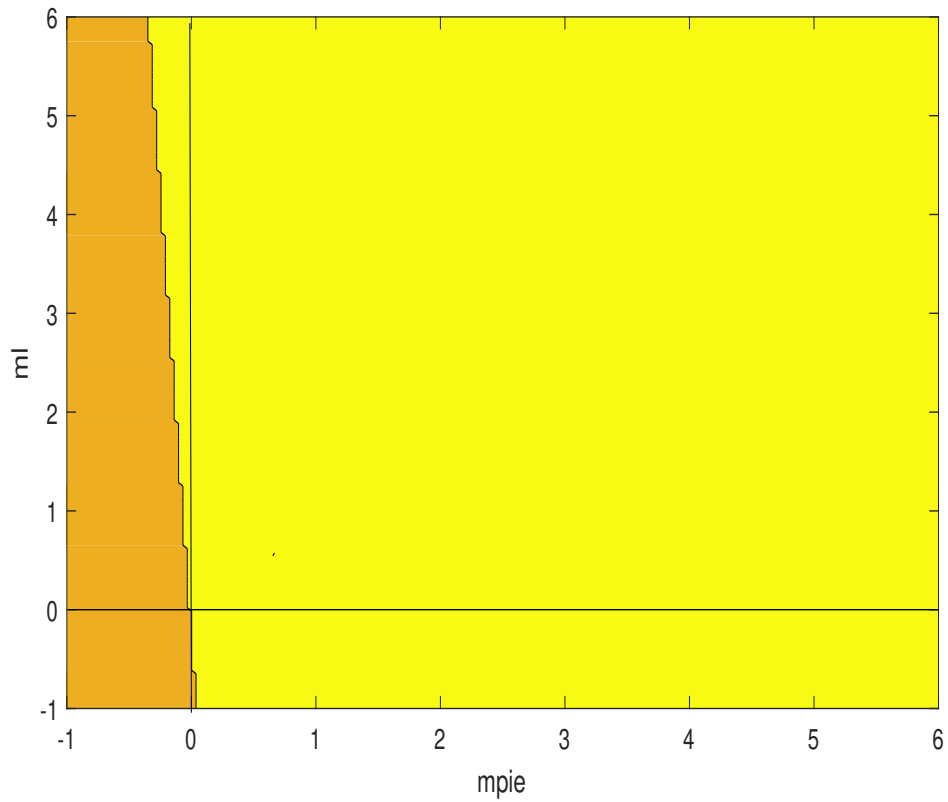
38

ZLBD-Constrained Economy - Stronger Credit Response: m_c : solid = 0 / dashed = 2 / dotted = 8

Figure 8: Determinacy Regions for ZLB-Constrained and Unconstrained Economies

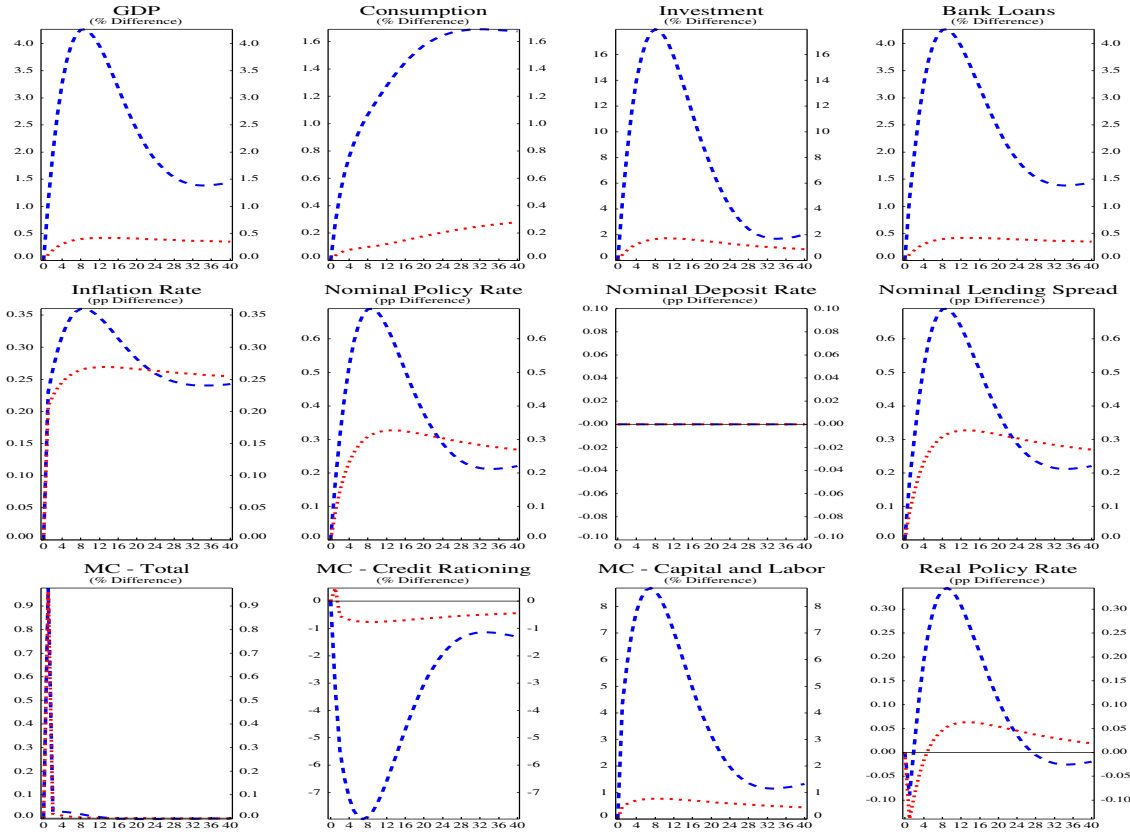


ZLBD-Constrained Economy - Spread Semi-Elasticity = 10 (yellow = BK-stable)

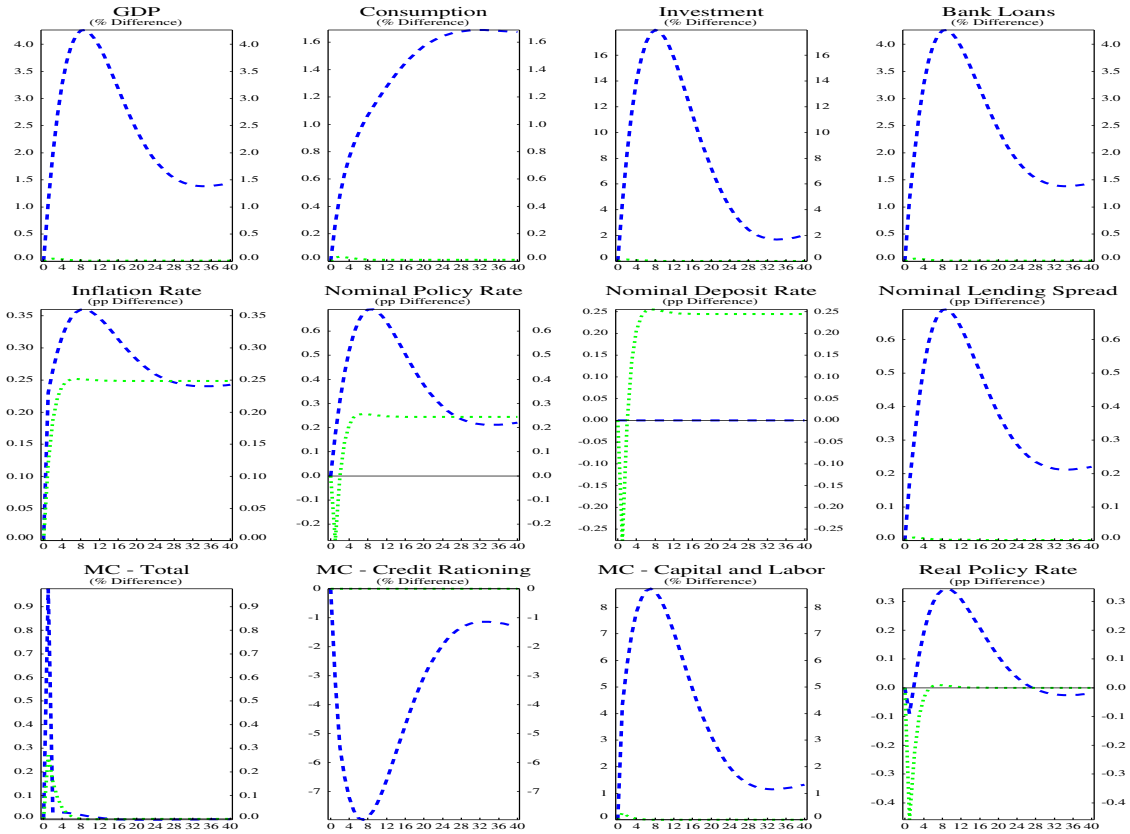


Unconstrained Economy - Spread Semi-Elasticity = 10 (yellow = BK-stable)

Figure 9: Permanent Inflation Target Shock



ZLBD-Constrained Economy (spread semi-elasticities: dashed = 5 / dotted = 1)



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ZLBD-Constrained (dashed) versus Unconstrained (dotted) Economy (spread semi-elasticity = 5)