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Banks, Money, and the Zero Lower Bound on Deposit Rates

Michael Kumhof[1]
Xuan Wang[2]

[1] Bank of England
[2] Vrije Universiteit Amsterdam

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Michael Kumhof *
Xuan Wang **

Abstract

We develop a New Keynesian model where all payments between agents require bank deposits through deposits-in-advance constraints, bank deposits are created through disbursement of bank loans, and banks face a convex lending cost. At the zero lower bound on deposit rates (ZLBD), changes in policy rates affect activity through both real interest rates and banks' net interest margins (NIM). At estimated credit supply elasticities, the Phillips curve is very flat at the ZLBD, because inflationary pressures increase NIM. This strongly increases credit and thereby output, but it dampens inflation by relaxing price setters' credit rationing constraint. At the ZLBD, monetary policy has far larger effects on output relative to inflation, and Taylor rules stabilize output less effectively than rules that also respond to credit. For post-COVID-19 policy, this suggests urgency in returning inflation to targets, avoidance of negative policy rates, and a strong influence of credit conditions on rate setting.

Keywords: Banks, money creation, inside money, money demand, deposits-in-advance, Phillips curve, zero lower bound, monetary policy rules, Taylor rules, post-COVID-19 reforms.

JEL Codes: E41, E44, E51, G21

* Corresponding author: Bank of England, Room TS-03-414, Threadneedle Street, London EC2R 8AH, UK, Tel.: +44-203-4613049, email: michael.kumhof@outlook.com.
** Vrije Universiteit Amsterdam and Tinbergen Institute. Tel.: +44-737-7401066, email: xuan.wang@economics.oxon.org.

1. Introduction

Since the Global Financial Crisis, there has been renewed interest in understanding the role of bank financing and deposit creation in the transmission of monetary policy. In the policy arena, an appreciation of the importance of bank financing has helped with the design of new tools for crisis management. For example, in combating the economic effects of COVID-19 on struggling businesses, the UK government has unveiled a package of £330bn in loans, totaling around 15% of UK GDP, to be made available through the banking system with the help of the Bank of England. The motivation is in large part to help overcome the reluctance of banks, under such severe economic conditions, to lend and create the purchasing power that is necessary for business transactions. Meanwhile, in academia a growing theoretical literature is reintroducing the notion of bank financing or of inside money creation, specifically the creation of deposits through the disbursement of new bank loans, into macroeconomic banking models. Recent advances include, but are not limited to, Jakab and Kumhof (2015, 2020), Piazzesi and Schneider (2018), Brunnermeier and Sannikov (2016), and Bianchi and Bigio (2014). In particular, Jakab and Kumhof (2020) show that aggregate banking sector balance sheets in four major advanced economies exhibit very large and rapid quarter-on-quarter changes, and that these changes are driven almost exclusively by changes in bank lending rather than by changes in bank securities holdings or in aggregate non-bank saving. They show that the bank financing channel is highly consistent with these phenomena.

This new work is well suited to complement existing New Keynesian models, by providing a more complete framework where both the financing channel and the traditional real interest rate channel of monetary policy transmission can be studied simultaneously. Our paper therefore incorporates deposit use via deposits-in-advance constraints that apply to all economic transactions, and deposit creation via bank credit whose magnitude depends on the net interest margin that banks are able to earn (financing channel), into an otherwise canonical infinite horizon New Keynesian DSGE model with sticky nominal goods prices and a role for monetary policy responses to inflation that affect the real interest rate (real interest rate channel).

While our theoretical focus is the incorporation of the financing channel into New Keynesian DSGE models, our policy focus is the post-crisis low interest rate environment. As suggested empirically by Bech and Malkhozov (2016), Heider et al. (2019), Lucas et al. (2019), and Goodhart and Kabiri (2019), and shown theoretically by Brunnermeier and Koby (2018), in a model where the banking system plays a different role from our model, lowering policy rates further when they are already very low can have detrimental effects. Section 2.3 contains additional references. The novel contribution of our model is its emphasis on the negative output effects of insufficient creation of purchasing power by the banking sector. In this model, both individual and aggregate purchasing power can be increased beyond prior income through deposit creation, and as a result bank financing is a far more critical determinant of macroeconomic outcomes than in standard banking models. This carries very important and timely messages for policy design, including for the specification of monetary policy rules.

While the literature has mostly emphasized the role of the zero lower bound on policy rates (ZLB), the key role in our paper is played by the zero lower bound on deposit rates (ZLBD). The relevance of the ZLBD friction is emphasized by the empirical work of Heider et al. (2019), who show that commercial banks generally do not push deposit rates into negative territory, and that while central banks can drive the policy rate to very low levels and even below zero, they are reluctant to do so because of the effects of the ZLBD on bank profitability. This is because the policy rate is generally the reference rate for lending rates. At the ZLBD it therefore directly affects the net interest margin, the difference between lending rates and deposit rates. In the data the net interest margin is generally positive even when the policy rate has reached the ZLB, because of additional lending margins whose size could for example depend on the market power of banks in the loans market as in Gerali et al. (2010). But the net interest margin may nevertheless be compressed when deposit rates have reached the ZLBD and the policy rate is sufficiently low.[1] In that case, when the policy rate is lowered further, the net interest margin and thus banks' incentive to lend are also reduced further. This exact concern has played a critical role in many recent policy decisions by central banks. For example, in 2016 the Bank of England voiced concerns that absent additional policy measures further reductions in policy rates might not be fully transmitted to the real economy, due to perverse effects on lending caused by an erosion in banks' net interest 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 lending incentives to banks.

Our model introduces a bank-based monetary payment system into an otherwise standard environment with representative firms and households, and a government. Households consume, supply labor and accumulate capital, firms own a technology to produce output using capital and labor, and government spends, taxes labor and issues bonds. Banks provide the economy's payment technology whereby all agents interact with each other through a sequence of deposits-in-advance constraints that cover every single payment. Simplifying for the purpose of exposition, specifically omitting payments to and from government and interest payments to banks, the intra-period sequence of events is as follows: Firms obtain bank loans that are disbursed to them in the form of new deposits. Firms then use their new deposits to purchase capital and labor from households - this is when inside money enters the economy. In the next step output is produced. Households then use the deposits that they acquired in exchange for labor and capital in order to purchase this output for consumption. Firms therefore receive their sales revenue in the form of deposits. Finally, firms use these deposits to repay their loans - this is when inside money exits the economy. In the model this happens for an instant at the end of each period. In the real world many such production and payment cycles overlap, so that bank balance sheets never vanish, even for an instant.

Banks are unique in their ability to offer a payment system, because only banks are able to credibly commit to honoring their IOUs vis-à-vis any subsequent holder, thereby making these IOUs acceptable as a universal medium of exchange. The main reason why banks have this unique status is their support by the system of central banks and regulatory agencies (Goodhart (1988)). In our model bank deposits are therefore risk-free, and are the only circulating medium of exchange.

We model deposits-in-advance constraints in a similar manner to Shapley and Shubik (1977) and Lucas and Stokey (1987). Bank deposits are sometimes referred to in the literature as inside money, which together with outside money and interest rate rules help to establish equilibrium existence and nominal determinacy in a general equilibrium with incomplete markets (Dubey and Geanakoplos (2003, 2006), Tsomocos (2008)). In our model, central bank money, namely the reserves that banks require for interbank settlement, is inside money. Outside money is not required for determinacy, which is instead established as in standard New Keynesian models, through a policy interest rate rule in the presence of sticky goods prices. However, the presence of commercial bank money affects the determinacy regions that apply to such policy rules, especially at the ZLBD.

[1] Our model abstracts from lending margins altogether to keep the analysis tractable. The *level* of the policy rate can therefore not reach the ZLB. But this is not critical for our analysis, which focuses on the effect of *changes* in the policy rate when net interest margins are already compressed at the ZLBD.

In this model, two features are important for the determination of interest rates. First, commercial banks can sell their loans to the central bank, to obtain reserves that pay the policy rate. By arbitrage, the interest rate on loans must therefore equal the policy rate. This is in line with the empirical evidence in Ippolito et al. (2018), who show that the floating rates of bank loans are tied to monetary policy rates. Second, commercial banks incur a convex cost of making loans, similar to Curdia and Woodford (2010) and Eggertsson et al. (2017), and at the margin the net interest margin, the difference between loan and deposit rates, has to be sufficient to cover this cost. By arbitrage, the deposit rate in our model must therefore be lower than the policy rate. This is in line with the empirical evidence in Drechsler et al. (2017), who document, for the US, that there is a wide spread between the Fed funds rate and the household deposit rate, and furthermore that there is a positive correlation between the policy rate and the spread between the policy rate and the household deposit rate during normal economic times (i.e., away from the ZLBD), due to sticky deposit rates. Because we mainly focus on the ZLBD period, we also obtain this positive correlation, even though sticky deposit rates are absent from our model.

We compare the behavior of the ZLBD-constrained economy to that of an otherwise identical unconstrained economy. The key difference is the role played by banks' loan supply curve, which relates the amount of credit banks are willing to extend to the net interest margin they are able to earn. At the ZLBD, deposit interest rates cannot adjust, and any change in the policy rate leads to a one-for-one change in the net interest margin. This change is exogenous for banks, and it exogenously changes their ability to cover the cost of making loans.[2] As a result, the creation of loans and deposits responds highly inelastically to changes in credit demand. Solving for the equilibrium of the ZLBD-constrained economy applies the concepts of equilibria with quantity rationing of Benassy (1990, 1993) and Drèze (1975). Specifically, the loan supply curve becomes a credit rationing constraint, because the net interest margin cannot increase to allow banks to satisfy borrowing firms' additional demand for credit. Borrower optimization problems that are subject to constraints imposed by lender behavior are very common in the literature, with Carlstrom and Fuerst (1997) and Bernanke et al. (1999) perhaps the most well-known examples. In the unconstrained economy, deposit interest rates adjust to achieve the spread that banks require in order to cover the cost of making loans. As a result, the creation of loans and deposits responds highly elastically to changes in credit demand. Solving for the equilibrium of this economy is straightforward, as the deposit rate clears the credit market without credit rationing.

We use our model to show that at the ZLBD the output-inflation trade-off is dominated by a very flat steady state Phillips curve. The reason is the financing channel of monetary policy, whereby reductions in inflationary pressures that lead to reductions in nominal interest rates must also reduce net interest margins. We find that with a strong financing channel, these have large negative effects on credit and output, while at the same time acting as cost-push shocks that limit the overall drop in prices.

A critical determinant of the size of the output response is the semi-elasticity of credit supply with respect to the net interest margin. The basis of our calibration of this semi-elasticity is an IV estimation using US data. We find that bank lending contracts by 10% when net interest margins decline by 1 percentage point. This implies that, at the ZLBD, the financing channel of monetary policy is very strong relative to the real interest rate channel. Output responses to shocks near the ZLBD are therefore significantly amplified relative to the unconstrained economy.

[2] In practice one response of banks to the ZLBD has been to increase lending margins. But, as we will show later (Figure 2), the scope to do so has been limited. Lending margins are absent in our model.

The determinants of inflation in the ZLBD-constrained economy include not only the traditional marginal cost terms, user costs and wages, but also the multiplier of the credit rationing constraint. Disinflationary shocks and the accompanying drops in the policy rate are therefore characterized not only by a drop in traditional marginal cost terms but also by much tighter conditions on bank financing, or external cash flow. This has an inflationary rather than a deflationary effect, because it gives producers an incentive to generate sufficient internal cash flow, by charging higher prices. This implies that the inflation response to shocks near the ZLBD is much more subdued than in the unconstrained economy.

We use this framework to establish the following results for ZLBD-constrained economies. First, monetary policy has far larger output effects and far smaller inflation effects than in unconstrained economies. Over the medium term, even a small permanent increase in the nominal policy rate due to higher steady state inflation facilitates a large permanent expansion in credit and output. The current efforts of central banks to return inflation rates to their medium term targets are therefore extremely important. In the meantime, even a modest temporary monetary easing facilitates a sizeable temporary expansion in credit and output at a modest cost in terms of inflation. While the argument that higher inflation can help to get an economy out of a deep recession is not new, our transmission mechanism, from inflation to nominal interest rates to net interest margins to deposit creation to economic exchange to real activity, is new. Second, the *ceteris paribus* output effects of Taylor-type changes in monetary policy rates in response to changes in inflation are the opposite of unconstrained economies. For example, a reduction in policy rates in response to lower inflation following a contractionary demand shock makes the shock more rather than less contractionary. This suggests that central banks should exercise great caution in pushing policy rates into negative territory. Third, modifications of monetary policy rules that emphasize responses to reductions in credit through monetary easing, while maintaining Taylor-type responses to inflation, make monetary policy far more effective at stabilizing output, consumption and hours worked. This suggests that central banks should not only pay attention to the interactions of their rate setting decisions with inflation and output, but also with banks' net interest margins and thereby with credit conditions.

Policy at the ZLBD therefore has new and significantly stronger levers. The reason is that with the financing channel the level of aggregate expenditure is determined directly[3] by the quantity of bank-created purchasing power. Bank financing is therefore a far more critical determinant of macroeconomic outcomes than in other macroeconomic models. Without the financing channel, an individual agent's purchasing power is constrained to equal that agent's prior income plus income transferred from other agents through borrowing. However, because any debt-financed increase in the purchasing power of the borrower is offset by the diminished purchasing power of the lender, at the aggregate level purchasing power is necessarily constrained by prior income. The key insight is that in modern financial economies, with widespread access to bank credit, non-banks are not constrained in this way. Instead they are constrained by deposits-in-advance constraints that limit their purchasing power to their deposits rather than their income. Deposits in turn equal the sum of prior income, income transferred from other agents through borrowing, and crucially, net new deposit creation through new loans. New deposits are created in ledgers, through an equal increase in the assets and the liabilities of the banking sector, and are therefore not directly dependent on prior income.[4] This does not imply that banks allow agents to violate the economy's overall

[3] The deposits-in-advance specification makes the financing channel especially strong, but the same qualitative results would continue to hold for other money demand specifications.

[4] There could of course be an indirect dependence, to the extent that prior income affects the willingness of banks

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.

We also emphasize another feature of our model, the endogenous strong comovement between consumption and investment at the ZLBD. The reason is that the ZLBD constrains the overall quantity of deposits, with its allocation between consumption and investment purchases left to the market. An overall shortage of deposits will therefore tend to affect both sectors in the same way.

Discussions of banking still frequently appeal to the deposit multiplier model, which argues that the size of bank balance sheets is a multiple of the policy-determined quantity of central bank money. However, modern central banks invariably target interest rates. During normal times they are therefore committed to supplying as much cash and reserves as households and banks demand at that rate, while during a QE period the quantity of reserves exceeds banks' demand, and is therefore also not a direct determinant of the quantity of private money creation in the sense of the deposit multiplier model, while cash remains demand determined. Therefore, in our model cash is not present at all, while the quantities of both deposit money and central bank reserves are determined by the interaction of the profit-maximizing decisions of banks and their customers.

The rest of the paper is organized as follows. Section 2 reviews the related theoretical and empirical literature. Section 3 presents empirical evidence on the semi-elasticity of credit supply with respect to the net interest margin. 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 five strands of literature that are related to our paper. Section 2.1 reviews the recent theoretical macro literature on deposit creation through bank credit. Section 2.2 discusses the literature on inside money in general equilibrium with incomplete markets. Section 2.3 lists literature on the distinction between aggregate income and aggregate purchasing power. Section 2.4 reviews the literature on contractionary reductions in nominal policy interest rates in low-interest economies. Section 2.5 discusses the literature on the flattening of the Phillips curve.

2.1. Macroeconomic Models with Financial Frictions

Recent DSGE models of monetary economies have increasingly adopted the so-called cashless limit assumption, whereby the transmission of monetary policy can be thought of exclusively in terms of interest rates (Woodford (2003)), and have therefore omitted monetary aggregates altogether. By contrast, the preceding and still actively used model generation has a central role for money. Its key features are that, first, money is demanded because of a cash-in-advance constraint, money in the utility function or transactions cost technology, and that, second, the only money is government fiat money. 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). Our work can instead be seen as an attempt to improve upon the second feature. Our motivation is that in modern economies government fiat money in circulation, or narrow money, accounts for only a very small fraction (3% in the case of the UK) of the broad money supply, with the liabilities of

to lend and of non-banks to borrow. But that willingness is dependent on many other and more important factors, such as expected future income and available collateral.

commercial banks and other financial institutions accounting for the remainder (97%). One of the two key novel features of our model is therefore to have broad rather than narrow money enter the money demand function. The second novel feature is to present the optimizing calculus whereby both banks and their customers decide on the creation of that money through loans. Thus, banks must play a central role in the analysis.

In this broad sense, our paper is therefore part of the extensive literature of DSGE models with financial frictions. Some of the outstanding contributions to this literature include Kiyotaki and Moore (1997), Bernanke et al. (1999), Iacoviello (2005), Gerali et al. (2010), Cúrdia and Woodford (2010), de Fiore et al. (2011), Gertler and Karadi (2011), Gertler and Kiyotaki (2011), Jermann and Quadrini (2012), Adrian and Boyarchenko (2013), Christiano et al. (2014), Clerc et al. (2015), Nelson et al. (2015), Justiniano et al. (2015), Benes and Kumhof (2015), Boissay et al. (2016), Eggertsson et al. (2017) and Nuño and Thomas (2017).[5]

However, the nature of the financial friction that is studied in our model is different. The critical model feature is not banks' optimization problem, which could take any of the forms adopted in the above-mentioned papers. Nor is it the fact that bank liabilities function as money, which is important in our model but does not suffice to make it a financing model.[6] Rather, the critical feature is the role played by both bank assets and bank liabilities in the constraints facing banks' customers. Specifically, banks initially create deposits through loans for a single agent that requires deposits for real economic transactions, and thereafter provide a payment system whereby these deposits continue to circulate and are required for all economic transactions. Our paper is therefore closely related to a recent macroeconomic literature that models deposit creation through bank loans in general equilibrium,[7] including Goodfriend and McCallum (2007), Jakab and Kumhof (2015, 2020), Faure and Gersbach (2017) and Clancy and Merola 2017). This literature has a long pedigree in the Keynesian and Post-Keynesian traditions, which are discussed in Section 2.3.

In Goodfriend and McCallum (2007), loans create deposits that enter a deposits-in-advance constraint on consumption. This work differs from ours in several dimensions. First, banks interact with a representative household rather than facilitating payments between multiple agents. Second, all transactions other than consumption do not require bank deposits. 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, 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 banking models without the financing channel. This is related to the result in Jakab and Kumhof (2015, 2020) that the deterministic steady states of these two model classes are identical. Clancy and Merola (2017) study macroprudential rules in small open economies in a variant of the bank financing model of Benes et al. (2014a,b).

The bank financing mechanisms is also being incorporated into the DSGE models of several 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 Karmelavicius (2018)), Norges Bank (Kravik and Paulsen (2017)) and

[5]Because this literature is large, the list of papers is necessarily incomplete.

[6]There is in fact a large number of papers where bank liabilities function as money. For a recent example, see Piazzesi et al. (2019).

[7]In this paper, we use *deposits* and *inside money* interchangeably.

People's Bank of China (Sun and He (2018)). Non-technical explanations of money creation through the banking system have recently been offered by the Bank of England (McLeay et al. (2014a,b)), the Bank for International Settlements (see e.g. Borio and Disyatat (2011, 2015)), the Bundesbank (Bundesbank (2017)) and the Reserve Bank of Australia (Doherty et al. (2018)). Another useful source is the excellent overview of the credit mechanics approach by Decker and Goodhart (2018).

In another part of the recent literature banks' deposits creation via loans plays a role, but it does so alongside other mechanisms. The 3-period model of Donaldson et al. (2018) is based on a combination of the financing mechanism with other mechanisms for balance sheet growth. As in financing models, banks issue book money ("fake receipts") through risky lending. But banks also need to function as warehouses that issue commodity money ("commodities receipts"), because warehoused commodities are required as collateral. 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. 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 bankers still settle their deposit contracts using the physical returns on their assets, 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. Inside Money in General Equilibrium with Incomplete Markets

Our paper is related to monetary theories of general equilibrium with incomplete markets. These theories of inside money, or of "loans creating deposits", have very early antecedents in the literature, including Macleod (1866), Wicksell (1906), Hahn (1920), Hawtrey (1919), Keynes (1931) and Schumpeter (1934, 1954). In this literature, there is an assumed requirement that money must be used to carry out transactions, formalized through cash-in-advance constraints similar to Grandmont and Younes (1972, 1973). Contributions to this literature include Dubey and Geanakoplos (2003, 2006), Bloise et al. (2005), Bloise and Polemarchakis (2006), Tsomocos (2003), Goodhart et al. (2006, 2013) and Wang (2019).

2.3. Income, Credit and Purchasing Power

Financing models emphasize that aggregate purchasing power equals prior aggregate income plus net new credit. The latter, by mobilizing resources that would otherwise have remained idle, triggers increases in the economy's post-loan income, while ex-post spending must equal ex-post income. This emphasis on the distinction between income and purchasing power can be traced back to Schumpeter (1934), Keynes (1939) and Kaldor (1989). The 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.[8]

[8] Bhattacharya et al. (2015) formalise some of Minsky's intuition, by modeling endogenous default and endogenous demand for credit and money.

2.4. 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 *ceteris paribus* reduces output. The reason is that it reduces bank lending rates and thereby net interest margins, 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 credit 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 exogenously 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 rather than created through loan financing, and that they 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 increases banks' quarterly earnings, and that this is in turn associated with stronger bank lending. This is consistent with our theoretical predictions. Heider et al. (2019) 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 these effects are 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.

2.5. 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 gains in central bank 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 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

An estimate of the semi-elasticity of credit supply with respect to the net interest margin is a key input into our model calibration and simulation. We collect quarterly US data for 1997Q1 - 2017Q1 from the Federal Reserve Bank of St. Louis, Call Reports, Datastream, and the Fed Loan Survey. The dependent variable *lnrealciloan* is the log of real commercial and industrial (C&I) loans from the US Flow of Funds. The corresponding spread *cispreadnet* is the spread on C&I loans net of smoothed charge-offs. This is a FISIM interest rate spread calculated using the methodology of Hood (2013).[9] The advantage of using a FISIM spread is that it approximates the average interest rate spread on the entirety of C&I loans. To control for endogeneity, we use 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 to large and medium firms in the Fed loan survey ($DEMAND$). The latter turns out to be the best IV according to standard criteria, with a 4-quarter lag giving the best fit. We introduce three controls that shift the supply of C&I loans independently of the spread, the one-quarter lags of the growth rate of real GDP (Δgdp), of banks' liquid assets (securities+cash+repo) to total assets ratio (*liquidity*), and of the percentage of banks reporting tightening lending standards to large and medium firms (*supply*).

Table 1 reports estimation results for the instrument $DEMAND_{t-4}$.[10] 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 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 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 closing the remaining gap to the ZLBD and lending rates starting to exhibit a somewhat larger spread relative to the Fed Funds rate. However, both processes took several years, and even by 2016 lending 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.

[9] FISIM stands for Financial Intermediation Services Indirectly Measured in the System of National Accounts. It is measured by multiplying loans and deposits by FISIM loan and FISIM deposit rate margins relative to a common reference rate. We are grateful to Kyle Hood for his support in performing the FISIM calculations.

[10] With the other instruments, the estimated elasticity is as large or larger than the one reported in Table 2.

4. The Model

4.1. Overview

The model economy consists of four sets of agents, banks, firms, households and the government. One period represents one quarter. Upper/lower case symbols represent nominal/real variables, and steady states are denoted by a bar above the respective variable. For simplicity we assume that the trend real growth rate equals zero. A separate Technical Appendix contains full derivations of all results.

The economy is intertemporally linked through households' holdings of government bonds and physical capital. However, the issuance and retirement of deposit money by banks is purely intratemporal, with new deposits created by banks through loan issuance at the beginning of each period, and the same deposits extinguished through loan repayments at the end of that period. Figure 3 summarizes the timeline, and Figure 4 shows the intra-period flows of physical resources and corresponding deposit payments between agents.[11] Each period begins with the realization of aggregate shocks. Next, 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 non-defaultable. Banks subsequently provide a retail payment system that firms, households and government must use to make payments to each other by way of deposit transfers. The government/central bank provides another wholesale payment system that banks must use to make payments of central bank reserves to each other. Individual banks face random deposit withdrawals to other banks. To settle such withdrawals, banks can borrow reserves from the central bank, and then transfer those reserves to the banks that receive the withdrawals, who in turn deposit them at the central bank. The government sets the monetary policy rate i_t, the uniform rate that the government pays on its liabilities and at which it will lend reserves to banks.

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 dividends[12] 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.[13] Households, after receiving deposits from firms, are subject to a deposits-in-advance constraint whereby they need to use deposits to make payments ahead of consuming commodities. They make payments for private consumption, private investment and investment adjustment costs to firms. They also need to make payments (labor income taxes, purchases of net new government bonds) to government by way of deposits. Government, once it has received these deposits, needs to use them to make payments to firms (government consumption) and households (interest on government debt). 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.

In our model, households and government, unlike firms, do not have access to credit but only to the payment system. Their principal constraints state that expenditure has to be less than or equal to

[11] Assuming that loans and deposits are issued and retired intra-period contributes greatly to analytical tractability, and is very common in the literature. For examples, see Gomes et al. (2003), Berentsen and Waller (2011), and Rocheteau et al. (2018).

[12] It 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.

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

prior income, in what may be called "income-in-advance" constraints. In practice, all sectors have some access to credit, and are therefore instead subject to deposits-in-advance rather than income-in-advance constraints. We therefore refer even to the constraints of households and government as deposits-in-advance constraints. The problems of these sectors could be generalized to allow for access to credit, but this would make the model less transparent.

4.2. Banks

There is a continuum of banks of measure 1, with an individual bank indexed by z. Credit creation is performed exclusively for firms and exclusively at the beginning of each period. Each bank offers the same amount of credit to every firm. Bank loans $L_t(z)$ that charge an interest rate i_t^ℓ create deposit money $D_t(z)$ that pays an interest rate i_t^d, subject to an increasing and convex cost of lending $C(L_t(z))$. We adopt a specific functional form for $C(L_t(z))$ that can be easily calibrated using the estimation results of Section 3. Credit supply functions of this kind have been commonly used in the recent literature. For a well-known example see Cúrdia and Woodford (2010), who adopt the same functional form and the same calibration that we use below. For another recent example see Eggertsson et al. (2017). We do not take a stand on the underlying credit supply friction. Possible candidates include transaction costs such as the time and effort spent in the processing of loan applications by a finite workforce, and regulatory costs that are increasing in the size of banks' balance sheets given finite bank equity, as argued in Curdia and Woodford (2010).[14] Other candidates include the agency frictions of financial intermediation that have been much emphasized in the macro-finance literature (Bernanke et al. (1999), Lorenzoni (2008), Gertler and Karadi (2011), Martinez-Miera and Repullo (2017)).

Banks are ex ante identical, and at the beginning of each period make identical decisions on the level of loans, so that $L_t(z) = L_t \; \forall z$. Furthermore, at the beginning of each period $D_t(z) = L_t(z)$. Banks are subsequently subject to exogenous, mean zero, i.i.d., intra-period deposit withdrawal shocks $\Delta D_t(z)$ that are sufficiently small ensure that $\Delta D_t(z) > -D_t(z) \; \forall z$. These shocks necessarily net to zero over all banks, $\int_0^1 \Delta D_t(z)dz = 0$, because a deposit lost to one bank is necessarily a deposit gained by another, recipient bank. As a result we must have $D_t = L_t$ at the aggregate level, which states that in our economy money equals loans, or credit.

Central bank reserves, $S_t(z)$, must be used to settle deposit withdrawal shocks, with $S_t(z) = \Delta D_t(z)$. Individual banks either borrow reserves from or deposit reserves at the central bank at the policy rate i_t. Banks that end up long in the deposit market therefore obtain positive intra-period reserves on the asset side of their balance sheets, while banks that end up short in the deposit market must first borrow reserves from the central bank and then immediately hand those reserves over to settle with the recipient bank, with no reserves remaining on the asset side of their balance sheet.

Following settlement of deposit withdrawals, additional central bank reserves, $\Delta S_t(z)$, can be obtained by banks at their own discretion, either from the central bank or from other banks that have positive reserve balances. Following central bank practice, we assume that central banks only accept the retail liabilities of non-banks in exchange for additional reserves, and we assume that other banks do the same. Banks that wish to obtain further reserves cannot therefore sell their own retail deposit liabilities, $D_t(z)$, to the central bank, and must instead sell part of their loans,

[14] These authors argue that a "convex technology ... corresponds to the idea of a finite lending capacity at a given point in time, due to scarce factors such as intermediary capital and expertise."

$\Delta L_t(z)$, which are liabilities of firms, with $\Delta S_t(z) = \Delta L_t(z)$. Such operations swap the gross interest earned on the loans that are sold $i_t^\ell \Delta L_t(z)$ against the gross interest earned on the reserves that are bought $i_t \Delta S_t(z)$.[15] The intra-period balance sheet identity for an individual bank after the conclusion of all reserve operations is

$$L_t(z) - \Delta L_t(z) + \Delta S_t(z) + S_t(z) = D_t(z) + \Delta D_t(z) \ . \tag{1}$$

Each bank's profits $\Pi_t^b(z)$ consist of three common terms, the interest margin between loan and deposit rates on the bank's original loans $\left(i_t^\ell - i_t^d\right) L_t(z)$, minus the cost of making loans $C(L_t(z))$, minus the interest margin between loan and policy rates on sales of loans in exchange for reserves $\left(i_t^\ell - i_t\right) \Delta L_t(z)$. A fourth term is either the interest margin between the policy and deposit rates on deposits gained, or the interest margin between the loan and policy rates on deposits lost. Note that this fourth term is completely exogenous to each bank, because the size of the deposit withdrawal is exogenous. Each bank therefore only makes decisions on its original level of loans and on its loan sales. We therefore have

$$\begin{aligned} \underset{L_t(z),\Delta L_t(z)}{Max} \ \Pi_t^b(z) \ &= \ \left(i_t^\ell - i_t^d\right) L_t(z) - C(L_t(z)) - \left(i_t^\ell - i_t\right) \Delta L_t(z) \\ &\quad + \left(i_t - i_t^d\right) \Delta D_t(z)|_{\Delta D_t(z)>0} + \left(i_t^\ell - i_t\right) \Delta D_t(z)|_{\Delta D_t(z)<0} \ . \end{aligned} \tag{2}$$

The first order condition with respect to $\Delta L_t(z)$ is

$$i_t^\ell = i_t \ . \tag{3}$$

The policy rate therefore passes through to the loan rate one for one. This is in line with the theoretical results in Peiris and Polemarchakis (2017) and Brunnermeier and Koby (2018). It is also supported by the empirical evidence of Ippolito et al. (2018) that floating loan rates are tied to the policy rate.

The cost of making loans $C(L_t(z))$ is assumed to be increasing at an increasing rate in the quantity of loans:

$$C(L_t(z)) = \frac{\kappa}{1+\frac{1}{\xi}} P_t \omega \left(\frac{L_t(z)}{P_t \omega} \right)^{1+\frac{1}{\xi}} \ . \tag{4}$$

Here ω is a scale parameter and ξ determines the spread semi-elasticity of credit supply. For simplicity we assume that $C(L_t(z))$ represents a lump-sum transfer to households rather than a resource cost. Because banks also transfer their profits to households, aggregate lump-sum receipts of households from banks equal $\left(i_t^\ell - i_t^d\right) L_t$. Given symmetry in banks' lending decisions and (3), the optimality condition for loans, in real terms, is given by

$$\ell_t = \omega \left(\frac{i_t - i_t^d}{\kappa} \right)^{\xi} \ , \tag{5}$$

where $i_t^d = 1$ at the ZLBD. This result requires a positive spread between the policy rate and the deposit rate, which is consistent with the empirical results of Drechsler et al. (2017).

Condition (5) shows that in the unconstrained economy credit supply responds highly elastically to credit demand, as i_t^d can adjust freely, and is determined in equilibrium so that the bank

[15] The central bank and commercial banks are assumed to collect interest on such loan portfolios at the same time, and the central bank immediately passes the interest on reserves on to its holders.

accommodates credit demand while making zero profits at the margin. Condition (5) also shows that in the ZLBD-constrained economy credit supply responds highly inelastically to credit demand, as the quantity of 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 mainly determines the size of the quantity response of credit at the ZLBD, while it mainly determines the size of the deposit interest rate response away from the ZLBD. The equation (5) can be used to compute the semi-elasticity of credit supply with respect to the net interest margin, $\varepsilon = d\ln(\ell_t)/d\hat{\imath}_t$, where $\hat{\imath}_t = \left(i_t - i_t^d\right) * 400$, as a function of ξ.

Deposits circulate between multiple agents inside each period. This necessarily makes the assignment of the recipient of the interest on deposits arbitrary. For simplicity we assume that all deposit interest is received by firms, so that the spread between loan and deposit rates enters in a single location in the model, namely in the Phillips curve. Firms pay this spread to rent the exclusive ability of banks to create a universally 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

$$G_{P,t}(j) = \frac{\phi_p}{2} y_t \left(\frac{\frac{P_t(j)}{P_{t-1}(j)}}{\pi_{t-1}} - 1 \right)^2 , \tag{6}$$

where ϕ_p calibrates the degree of inflation stickiness. $G_{P,t}(j)$ is a real resource cost, and firms purchase these resources from each other by paying each other in deposits. Each firm hires labor $h_t(j)$ and capital $K_t(j)$ at competitive nominal/real prices W_t/w_t and R_t^k/r_t^k. Aggregate labor h_t and capital K_t are integrals over $h_t(j)$ and $K_t(j)$, respectively. The firm obtains loans $L_t(j)$ to obtain deposits $D_t(j)$ that satisfy a deposits-in-advance constraint. Using the equality $D_t(j) = L_t(j)$, the nominal profit of firm j is therefore given by[16]

$$\Pi_t^F(j) = P_t(j)y_t(j) - W_t h_t(j) - R_t^k K_t(j) - L_t(j)(i_t^\ell - i_t^d) - P_t G_{P,t}(j) . \tag{7}$$

The deposits-in-advance constraint of firm j is

$$L_t(j) \geqslant L_t(j)(i_t^\ell - i_t^d) + W_t h_t(j) + R_t^k K_t(j) + \Pi_t^F(j) . \tag{8}$$

The left-hand side represents the total purchasing power generated for the firm by the bank. The right-hand side represents the payments that need to be made with these deposits ahead of production. We adopt the notation $D_t^{hb}(j) = L_t(j)(i_t^\ell - i_t^d)$ (deposits needed to cover net interest payments, which are first 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 needed to cover wage and user cost payments, which are received by households from firms) and $D_t^{hm}(j) = \Pi_t^F(j)$ (deposits needed 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

[16] In steady state these profits are principally due to the markups of monopolistically competitive firms.

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 (5) and the Inada conditions on consumption utility - recall that there could be no production, and therefore no consumption, in the complete absence of monetary exchange. For the remainder of this paper we will take note of the combination of prior income and net new credit that finances the spending of each group of agents. In the case of firms, their prior income before production equals zero, and it is *only* the extension of new credit that allows the production cycle to start.

Combining (7) and (8), we obtain the final form of the deposits-in-advance constraint:

$$L_t(j) \geqslant P_t(j) y_t(j) - P_t G_{P,t}(j) \ . \tag{9}$$

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

$$y_t^s(j) = S_t^a h_t(j)^{1-\alpha} K_t(j)^\alpha \ , \tag{10}$$

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

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

and in equilibrium $y_t^d(j) = y_t^s(j)$. The optimization problem of unconstrained firms is therefore

$$\begin{aligned} \underset{\{P_t(j),h_t(j),K_t(j),L_t(j)\}_{t=0}^\infty}{Max} \ E_0 \sum_{t=0}^\infty \beta^t \Lambda_t^h \Big[& \left(P_t(j)\right)^{1-\theta} \left(P_t\right)^\theta y_t - W_t h_t(j) - R_t^k K_t(j) - L_t(j)(i_t^\ell - i_t^d) \\ & - \frac{\phi_P}{2} P_t y_t \left(\frac{\frac{P_t(j)}{P_{t-1}(j)}}{\pi_{t-1}} - 1 \right)^2 - MC_t \left(\left(P_t(j)\right)^{-\theta} \left(P_t\right)^\theta y_t - S_t^a h_t(j)^{1-\alpha} K_t(j)^\alpha \right) \\ & + \eta_t^f \left(L_t(j) - \left(P_t(j)\right)^{1-\theta} \left(P_t\right)^\theta y_t + \frac{\phi_P}{2} P_t y_t \left(\frac{\frac{P_t(j)}{P_{t-1}(j)}}{\pi_{t-1}} - 1 \right)^2 \right) \Big] \ , \end{aligned} \tag{11}$$

where β is the household intertemporal discount factor and Λ_t^h is the multiplier of the household's nominal budget constraint, with the multiplier of the real budget constraint denoted by λ_t^h. The firm therefore maximizes the present discounted value of its profits subject to two 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 (9) must hold, with a multiplier of η_t^f.

The optimization problem of ZLBD-constrained firms sets $i_t^d = 1$ and adds to (11) a credit rationing constraint $L_t(j) \leq P_t \omega \left(\left(i_t^\ell - 1 \right) / \kappa \right)^\xi$. All terms on the right-hand side of this constraint are exogenous to the individual firm, so that this is an application of the concept of equilibria with quantity rationing of Benassy (1990, 1993) and Drèze (1975). Because each bank extends an equal amount of credit to every firm, all firms face identical constraints that take the same form as the aggregate credit rationing constraint (5). Denoting the multiplier of this constraint by $\eta_t^b \geq 0$, we therefore have a new term $-\eta_t^b \left(L_t(j) - P_t \omega \left(\left(i_t^\ell - 1 \right) / \kappa \right)^\xi \right)$ inside the square brackets of (11).

We will study equilibria where the credit rationing constraint is always binding, so that $\eta_t^b > 0$. Equilibrium changes in η_t^b will be seen to depend on relative strength of changes in credit supply and credit demand.

The firm's optimality conditions for capital and labor are standard, and are relegated to the Technical Appendix to conserve space. But the Phillips curve is now affected by credit rationing. Given symmetry across firms, we have

$$\frac{\mu mc_t}{(1-\eta_t^f)} - 1 = \phi_p\left(\mu-1\right)\left(\frac{\pi_t}{\pi_{t-1}}-1\right)\frac{\pi_t}{\pi_{t-1}} - \beta E_t \frac{\lambda_{t+1}^h}{\lambda_t^h}\frac{y_{t+1}}{y_t}\frac{(1-\eta_{t+1}^f)}{(1-\eta_t^f)}\phi_p\left(\mu-1\right)\left(\frac{\pi_{t+1}}{\pi_t}-1\right)\frac{\pi_{t+1}}{\pi_t} \; , \tag{12}$$

where mc_t is real marginal cost and $\mu = \theta/(\theta-1)$. The optimality conditions for loans in the unconstrained and ZLBD-constrained economies are

$$\begin{aligned} &\text{Unconstrained:} && 1-\eta_t^f = 1-\left(i_t^\ell - i_t^d\right) \; , \\ &\text{ZLBD-constrained:} && 1-\eta_t^f = 1-\left(i_t^\ell - 1\right) - \eta_t^b \; . \end{aligned} \tag{13}$$

In the unconstrained economy the Phillips curve is therefore directly affected only by the net interest margin $\left(i_t^\ell - i_t^d\right)$, and the deposit rate clears the credit market without credit rationing. In the ZLBD-constrained economy, in addition to the net interest margin $\left(i_t^\ell - 1\right)$, the multiplier on the credit rationing constraint enters, and frictions that raise η_t^b put upward pressure on prices and downward pressure on output.

4.4. Households

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

$$\underset{\{c_t(i),h_t(i),I_t(i),k_t(i),B_t(i)\}_{t=0}^{\infty}}{Max} E_0 \sum_{t=0}^{\infty} \beta^t [S_t^c (1-v)^{\frac{1}{\epsilon}} \frac{\left(c_t(i) - vc_{t-1}\right)^{1-\frac{1}{\epsilon}}}{1-\frac{1}{\epsilon}} - \frac{\chi}{1+\frac{1}{\zeta}} h_t(i)^{1+\frac{1}{\zeta}}] \; . \tag{14}$$

Utility maximization is subject to a sequence of deposits-in-advance constraints. Households are assumed to not have access to credit, so that their spending is financed entirely through prior income, which is received in the form of bank deposits. This consists of factor incomes $W_t h_t(i)$ and $R_t^k k_{t-1}(i)$ and lump-sum dividend incomes $D_t^{hm}(i)$ and $D_t^{hb}(i)$. 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:

$$W_t h_t(i) + R_t^k k_{t-1}(i) + D_t^{hm}(i) + D_t^{hb}(i) \geq B_t(i) - B_{t-1}(i) + W_t h_t(i) \tau_{L,t} \; . \tag{15}$$

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 $t+1$.[17] 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 $P_t c_t(i)$, investment $P_t I_t(i)$ and investment adjustment costs $P_t G_{I,t}(i)$. The latter is given by

$$G_{I,t}(i) = \frac{\phi_I}{2} I_t \left(\frac{I_t(i)}{I_{t-1}(i)} - 1 \right)^2 , \tag{16}$$

where ϕ_I calibrates the degree of investment inertia. $G_{I,t}(i)$ is a real resource cost, and households purchase these resources by paying deposits to firms. We therefore have

$$\begin{aligned} W_t h_t(i) + R_t^k k_{t-1}(i) + D_t^{hm}(i) + D_t^{hb}(i) - (B_t(i) - B_{t-1}(i) + W_t h_t(i)\tau_{L,t} - B_t(i)(i_t - 1)) \geq \\ P_t c_t(i) + P_t I_t(i) + P_t G_{I,t}(i) \ . \end{aligned} \tag{17}$$

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

$$k_t(i) = (1 - \delta)\, k_{t-1}(i) + I_t(i) \ , \tag{18}$$

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. They are shown in the Technical Appendix to conserve space.

4.5. Government

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

$$D_t^{gh} \geq B_t\,(i_t - 1) + P_t g_t \ . \tag{19}$$

Government spending is financed entirely through prior income received in the form of bank deposits, which in this case includes household income transferred to the 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 the government of borrowing to acquire idle and (for the 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 labor tax rate is determined by the fiscal rule

$$\tau_{L,t} - \bar{\tau}_L = f_b \left(\frac{b_t}{4 y_t} - \frac{\bar{b}}{4 \bar{y}} \right) , \tag{20}$$

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

$$i_t = \left(2 - \frac{\beta}{\bar{\pi}} \right) \left(\frac{\pi_t}{\bar{\pi}} \right)^{m_\pi} \left(\frac{\ell_t}{\bar{\ell}} \right)^{m_\ell} S_t^i \ . \tag{21}$$

[17] Note that the government cannot make these interest payments before it has collected deposits from households. This explains the absence of interest payments in households' first deposits-in-advance constraint, and their presence in the second constraint below.

Monetary policy shocks S_t^i follow a first-order autoregressive process. The target for gross inflation is denoted by $\bar{\pi}$. The target for the intra-period nominal interest rate $2 - \beta/\bar{\pi}$ follows from the steady state household optimality condition for bonds (see the Technical Appendix). The inflation gap and loans gap feedback coefficients are m_π and m_ℓ, and the Taylor principle corresponds to $m_\pi > 1$ when $m_\ell = 0$. We will set $m_\ell = 0$ except in Section 5.3. Given (9), the loans gap in our model behaves very similarly to the output gap, so that it is possible to interpret the final term as an output gap.[18] We nevertheless maintain the present notation to emphasize the importance of bank credit.

The monetary policy rule (21) is very simple, with no interest rate smoothing and a feedback to contemporaneous quarterly inflation. This is deliberate, as it makes our analysis of the financing channel of monetary policy transmission much more transparent. To limit the implied volatility of nominal interest rates in the unconstrained economy, we choose a fairly high calibrated value for the inflation feedback coefficient m_π. We note that variations in m_π have much weaker effects in the ZLBD-constrained economy.

4.6. Market Clearing and GDP

The goods market clearing condition is

$$y_t = c_t + I_t + g_t + G_{p,t} + G_{I,t} \ . \tag{22}$$

The market clearing condition for physical capital is

$$K_t = k_{t-1} \ . \tag{23}$$

And finally, real GDP is defined as

$$gdp_t = c_t + I_t + g_t \ . \tag{24}$$

4.7. Calibration

Table 2 presents the details of our model calibration. It distinguishes between calibrated parameter values in the ZLBD-constrained (fourth column) and unconstrained (fifth column) economies. We begin with elements that are common to both models, and then proceed to the elements that are different.

For preferences, we remain close to much of the macro literature by setting households' intertemporal elasticity of substitution to $\epsilon = 0.5$ and habit persistence to $v = 0.75$. The weight χ on hours in the utility function is set to normalize steady state labor supply to 1, and the labor supply elasticity is set at $\zeta = 1$. We will report results of sensitivity analysis for ϵ and ζ. For technologies, the production function parameter α is set to fix the steady state labor income to GDP ratio 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 labor 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

[18] Inflation adjustment costs are negligible in size.

state gross markup 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 set at $m_\pi = 3.0$ and $m_\ell = 0$. We will perform sensitivity analysis for these two coefficients. The persistence of first-order autoregressive shocks in our illustrative simulations is $\rho_i = 0.95$ for monetary policy shocks and $\rho_c = 0.7$ for consumption demand shocks (habit persistence imparts additional persistence to this shock). In our impulse responses the sizes of both shocks are chosen only for illustrative purposes. We also perform stochastic simulations under monetary policy shocks, where we set the standard deviation of the log of gross monetary policy shocks at 0.0015. This is at the lower end of the estimates provides by Christiano et al. (1999), Smets and Wouters (2007) and Christiano et al. (2015). With this calibration our ZLBD-constrained economy always remains well within the ZLBD-constrained region even after large shocks, while the probability that deposit rates in our unconstrained economy hit the ZLBD is negligibly small. This justifies our reliance on simulations that ignore the possibility of transitioning between the ZLBD-constrained and unconstrained economies. The final common element across models is the discount factor β, which is set to fix the steady state real policy interest rate at 2% per annum in both models. This implies very similar steady state real variables as we move between unconstrained and ZLBD-constrained economies.[19]

The differences between unconstrained and ZLBD-constrained economies are instead assumed to be due to differences in steady state inflation and deposit rates. In the unconstrained model, we set the inflation target $\bar{\pi}$ to obtain a steady state inflation rate of 2% per annum and thus a steady state nominal policy rate of 4% per annum. We set the parameter κ in the credit supply function to obtain a steady state deposit interest rate of 2% per annum. As a result, we must also have $\omega = \bar{\ell}$. Given this we then set the parameter ξ of the credit supply function to calibrate $\varepsilon = 10$. This is based on our estimation results, and identical to Cúrdia and Woodford (2010).

In the ZLBD-constrained model we assume that the economy features the same 2% net interest margin as in the unconstrained model, but at a lower level of nominal interest rates of 2% per annum. We adopt a two-step calibration procedure. In the first step, we specify a variant of the ZLBD-constrained model under the assumption that the credit rationing constraint ceases to bind, $\bar{\eta}^b = 0$, at a 4% nominal policy rate and a 0% deposit interest rate. We otherwise calibrate this hypothetical economy to match the same calibration targets as in the first paragraph above. We calibrate $\bar{\pi}$ to obtain steady state inflation rates and nominal interest rates of 2% and 4% per annum. We set the parameter κ to equal the 4% steady state net nominal interest rate, $\kappa = 1 - \beta/\bar{\pi}$. This implies that $\omega = \bar{\ell}$, and imposing $\bar{\eta}^b = 0$ pins down the level of $\bar{\ell}$. We again set ξ to calibrate $\varepsilon = 10$. We also consider two alternatives of $\varepsilon = 5$ and $\varepsilon = 2.5$. The case of $\varepsilon = 5$ might be realistic for the long run, because banks can to some extent adjust to lower net interest margins by changing their business models, for example through a greater share of fee-earning activities. The case of $\varepsilon = 2.5$ is only included for illustrative purposes.[20]

In the second step of the two step procedure, the parameters ϵ, v, χ, ζ, α, δ, μ, β, ω, κ and ξ remain unchanged. Only three parameters are adjusted to obtain steady states at lower net interest margins than 4%. First, government spending and the labor tax rate are adjusted to ensure that

[19] Otherwise there would for example be very large differences in steady state capital stocks.

[20] US Banks' net interest margin on commercial and industrial loans has in recent decades rarely exceeded 3.25%. With $\varepsilon = 2.5$, a 1 percentage point, or almost one third, reduction in that margin would lead banks to reduce lending by a mere 2.5%. This is not only inconsistent with the data but also highly implausible.

government spending and government debt continue to equal 18% and 100% of GDP in steady state, as not imposing this constraint would imply a highly implausible long-run value for the government debt to GDP ratio. Second, steady state inflation is lowered from 2% to a new baseline value of 0%, $\bar{\pi} = 1$, so that $\bar{\eta}^b > 0$. This reduces the quantity of credit and thereby all real activity. However, this reduction is somewhat larger than implied by $\varepsilon = 10.0$ / 5.0 / 2.5, which was calibrated at a 4% nominal interest rate. The reason is that the credit supply function is convex, so that it becomes significantly more elastic at significantly lower credit levels. Specifically, it increases to $\tilde{\varepsilon} = 15.0$ / 8.6 / 4.6 at a 2% nominal interest rate.

Lane (2019) and Acharya et al. (2020) discuss that since the GFC inflation in major economies has often and persistently been lower than central banks' inflation targets. They attribute this to the prolonged adjustment dynamics that characterize the aftermath of a major global financial crisis, and Lane (2019) argues that the targets represent a continued but medium term objective. Our interpretation of the ZLBD-constrained economy is motivated by this situation. We think of the central bank's current inflation target in the model as low compared to its medium-term target. In our dynamic simulations, all responses to current shocks are therefore modelled as occurring in a low-inflation steady state and therefore in a ZLBD-constrained environment. Similarly, in our steady state simulations we treat the low-inflation steady state as the benchmark to which other steady states are compared.

5. Model Analysis

In this section we study and compare the properties of the ZLBD-constrained and unconstrained economies. The first subsection studies the dependence of the ZLBD-constrained economy's steady state on changes in the nominal policy rate and net interest margin. The unconstrained economy is unaffected by such changes. The second subsection studies impulse responses for temporary monetary policy shocks, with a focus on the implied slopes of Phillips curves in ZLBD-constrained and unconstrained economies. The third subsection studies consumption demand shocks in ZLBD-constrained and unconstrained economies, with a focus on the role of the systematic component of monetary policy. In all our figures the black solid, blue dashed and red dotted lines show results for the ZLBD-constrained economy with $\varepsilon = 10$ / 5 / 2.5, and the green dashed lines show the unconstrained economy with $\varepsilon = 10$.

5.1. Steady State Analysis

In this subsection we study the effects of permanent changes in the nominal policy rate, through permanent changes in the inflation target $\bar{\pi}$, on the ZLBD-constrained economy's steady state equilibrium. We show that a permanent monetary tightening (lower $\bar{\pi}$) is highly contractionary, because the resulting lower net interest margin has large negative effects on credit and thereby on output, while at the same time acting as a cost-push term that limits the overall drop in prices. In other words, the financing channel implies a downward-sloping and very flat steady state Phillips curve.

5.1.1. A Simple Model: Analytical Results

Consider a version of the model with log consumption preferences, no habit persistence, a unitary labor supply elasticity, a production function that is linear in hours worked, and a fiscal sector without government spending and with lump-sum taxes that ensure that government debt remains equal to zero at all times. In this case the steady state of the economy is given by three equations, banks' credit supply function, households' marginal rate of substitution between consumption and hours worked, and firms' marginal cost. Furthermore, the steady state levels of loans, output, hours and consumption are equal. We use that equality to express all three equations in terms of hours worked, and obtain a system of three equations in three endogenous variables, $\bar{h}$, $\bar{w}$ and $\bar{\eta}^b$, with an exogenous policy variable $\bar{\imath}$:

$$\begin{aligned} \bar{h} &= \omega \left(\frac{\bar{\imath} - 1}{\kappa} \right)^{\xi} \\ \bar{w} &= \chi \bar{h}^2 \\ 1 &= \mu \frac{\bar{w}}{2 - \bar{\imath} - \bar{\eta}^b} \end{aligned} \tag{25}$$

The first equation shows that in the ZLBD-constrained economy a decrease in the steady state nominal interest rate directly reduces real economic activity through reduced lending and deposit creation. By the second equation this reduces the real wage, with the size of the reduction depending on both the intertemporal elasticity of substitution and the labor supply elasticity (both equal one in this simple example, which explains the exponent of 2 on $\bar{h}$). By the third equation, a lower real wage together with a lower policy rate increase the tightness of the credit rationing constraint $\bar{\eta}^b$. The rate at which output decreases with the net interest margin is only determined by the semi-elasticity ε, while the rate at which the wage and labor share of income $\bar{w}$ decrease is in addition dependent on preference elasticities.

On the other hand, if the nominal interest rate remains sufficiently high, banks can satisfy firms' loan demand without credit rationing so that $\bar{\eta}^b = 0$. In this case the first equation becomes $\bar{h} = \omega \left(\left(\bar{\imath} - \bar{\imath}^d \right) / \kappa \right)^{\xi}$ and the third equation becomes $1 = \mu \bar{w} / \left(1 - \bar{\imath} + \bar{\imath}^d \right)$. The equation system now determines $\bar{h}$, $\bar{w}$ and $\bar{\imath}^d$, and a higher steady state nominal policy rate has no effects on steady state economic activity.

5.1.2. The Full Model: Numerical Results

This logic of the simple model carries over to the steady state of the full model of Section 4. Figure 5 shows the evolution of the steady states of key endogenous variables of this model as the nominal policy rate varies between 1% and 5%, where 2% is the baseline and 4% is the point at which the ZLBD ceases to bind. The figure shows three different sets of results for three different ε. We will discuss Figure 5 in terms of a permanent decrease in the nominal policy rate from 4% to 2%, which halves banks' net interest margin. We will mainly comment on the intermediate credit supply elasticity of $\varepsilon = 5$, which as discussed earlier may be realistic as a description of the longer run behavior of the banking system.

The decrease in the nominal policy rate from 4% to 2% halves the net interest margin. This reduces the supply of loans by well over 15%. GDP drops one for one with reduced credit supply, while consumption drops by around two thirds of the decrease in GDP because the decrease in production is accompanied by a large decrease in the desired capital stock and therefore in investment. Because the contraction of bank credit does not allow the economy to fully utilize available resources, due to a lack of circulating payment medium, there is a 31% decrease in the capital stock and a 14% decrease in hours worked. The decrease in the capital stock is larger because the user cost of capital is constant in steady state, while the real wage declines sharply by 22%. Firms therefore utilize relatively more labor than capital, but due to the decline in the real wage the labor income share nevertheless declines by over 7 percentage point. In other words, permanent reductions in the policy rate not only negatively affect the overall level of economic activity, they also have very strong effects on the income distribution.

The bottom row of Figure 5 presents part of this information in the form of steady state Phillips curves for different ε. We observe that movements in the output gap are very large compared to movements in the inflation gap. In other words, the steady state Phillips curves are very flat, with an average slope of around -0.15 for $\varepsilon = 5$. As we will see later, this is the dominant factor behind the slope of Phillips curves in the stochastic economy. The Technical Appendix presents additional results for more elastic household preferences. This does not affect the results for aggregate activity, but it reduces the swing from the labor income share to the capital income share by 1 to 2 percentage points.

5.2. Transitory Monetary Policy Shocks and Phillips Curves

This subsection first presents impulse responses for contractionary monetary policy shocks, followed by the Phillips curves that are implied by monetary policy shocks. This and all subsequent impulse responses first illustrate the behavior of the ZLBD-constrained economy as a function of the semi-elasticity of credit supply, and then compare the behavior of the ZLBD-constrained economy to that of the unconstrained economy. This subsection shows that a temporary monetary tightening, because it either immediately or after a short transition leads to a lower policy rate due to lower inflation, is far more contractionary when it works through both the financing channel and the real interest rate channel. Because of the underlying steady state Phillips curve, the dynamic Phillips curve of a ZLBD-constrained economy is always far flatter than that of an unconstrained economy.

5.2.1. Transitory Monetary Policy Shocks

Figure 6 shows the simulated effects of a 100 basis point persistent ($\rho_i = 0.95$) increase in S_t^i in the ZLBD-constrained and unconstrained economies. The shock is contractionary and disinflationary in both economies, as in all New Keynesian models. However, at the ZLBD the magnitudes are very different.

In both the ZLBD-constrained and unconstrained economies the shock has broadly similar effects on real policy rates, which increase by around 25 basis points after four quarters, and which have a contractionary effect on real demand. As a result, inflation drops by around 35 basis points and this, either immediately or after a few quarters, leads to an overall decline in the nominal policy rate. The main difference between the two model classes concerns output - the contractionary effect is much larger in the ZLBD-constrained economy and reaches 1.5% after one year. The reason follows directly from our steady state analysis. Namely, the prolonged period of below trend inflation implies a prolonged period of below trend nominal policy rates and therefore of net interest margins. Given the high elasticity of credit supply to net interest margins, and the one-to-one dependence of output on credit supply, the financing channel therefore triggers a much larger contraction in output than in the unconstrained model, where the deposit rate can adjust to keep the net interest margin nearly constant.

We next address the question of why the drop in inflation in the ZLBD-constrained economy can be so small despite the very much larger drop in output. While lower output reduces the demand for capital and labor, and therefore user costs and wages, the overall impact on inflation also depends on the credit rationing constraint. In the ZLBD-constrained economy this 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 output reduces the demand for credit. But the reduction in the nominal policy rate reduces the net interest margin and thereby the supply of credit. It can be shown that, unless credit supply is extremely inelastic[21], credit supply decreases by much more than credit demand. This increases the credit rationing multiplier and thus, *ceteris paribus*, marginal cost and inflation. This offsets a very large part of the effect of lower user costs and wages on inflation. Firms factor the effects of much tighter credit conditions on external cash flow into their pricing decisions, in a quantity rationing equilibrium along the lines of Benassy (1990, 1993) and Drèze (1975), by raising prices to generate sufficient internal cash flow. In the unconstrained economy the financial friction plays virtually no role in marginal cost, and the real interest rate channel dominates the dynamics of output and inflation. As a result, even the much smaller reduction in user costs and wages is sufficient to produce a very similar inflation response to the ZLBD-constrained economy.

5.2.2. Phillips Curves

Figure 7 studies the shape of the Phillips curves implied by monetary policy shocks - we will comment on other shocks below. To do so we stochastically simulate the model for 10100 periods, drop the first 100 periods, and then display scatter plots that plot the negative of the output gap against the inflation gap for each period. As discussed in Section 4.7, for this exercise the standard deviation of the log of the gross monetary policy shock is set to 0.0015. The top four subplots show the Phillips curves, first for the three ZLBD-constrained economies with different semi-elasticities of credit supply, and then for the unconstrained economy. We observe that the Phillips curves of the ZLBD-constrained economies are far flatter, with slopes of between -0.17 and -0.23, than that of the unconstrained economy, which has a slope of -3.80. While the range of observed inflation rates is very similar, the range of output gaps in the ZLBD-constrained economies is far wider. The slopes of the dynamic Phillips curves of the ZLBD-constrained economies are very close to the slopes of the steady state Phillips curves that we displayed in Figure 5. This demonstrates that the financing channel is primarily responsible for the difference between model classes.

The bottom two subplots plot the nominal policy rate against the inflation gap, for the ZLBD-constrained and unconstrained economies with $\varepsilon = 10$. We recall that the steady state nominal interest rate equals 2% in the ZLBD-constrained economy and 4% in the unconstrained economy. We observe that nominal policy rates in the ZLBD-constrained economy remain throughout in a range between 1.5% and 2.5%, and therefore far away from the point where the ZLBD ceases to bind, which is at 4%. Nominal policy rates in the unconstrained economy are concentrated in a range between 2% and 6%, with a few outliers on each side. Given that nominal deposit rates remain approximately 2% below nominal policy rates, there is therefore a negligible probability (around 0.2%) that the unconstrained economy could hit the ZLBD.

We have also generated Phillips curves for consumption demand and technology shocks, but they are omitted to conserve space. The Phillips curves of ZLBD-constrained economies are again dominated by the negatively sloped and very flat steady state Phillips curves of Figure 5.

In terms of policy, both Figures 6 and 7 illustrate that in a ZLBD-constrained economy a temporarily easier monetary policy, by allowing for a temporarily higher inflation rate, can be far more expansionary than in an unconstrained economy. This is simply a corollary of our steady state results. It may nevertheless be relevant in a world where trend inflation remains stubbornly low.

[21] Our results continue to hold unless the elasticity of credit supply drops well below 1. They also hold for much smaller inflation feedback coefficients m_π.

5.3. Systematic Monetary Policy and Alternative Policy Rules

In this subsection we study the effects of the systematic component of monetary policy in the presence of shocks to aggregate demand. The Technical Appendix discusses technology shocks, which are omitted here to conserve space. Taylor-type rules with a systematic response to inflation rely on the real interest rate channel for their stabilizing effects. However, in a ZLBD-constrained economy the financing channel is more powerful than the real interest rate channel. Policy rules that take this into account, through $m_\ell > 0$, can therefore stabilize the large fluctuations in output, consumption and hours worked of that economy far more effectively.

5.3.1. Consumption Demand Shocks and Taylor Rules

The top half of Figure 8 shows the simulated effects of a shock to consumption preferences S_t^c in the ZLBD-constrained economy. The size of the shock is normalized to obtain an initial GDP contraction of 1%, while consumption drops by around 1.4%. The drop in aggregate demand leads to a reduction in the demand for capital and labor. This triggers a reduction in user costs and wages and therefore, *ceteris paribus*, in inflation. This disinflationary pressure has highly contractionary effects in the ZLBD-constrained economy because, with a Taylor-type monetary policy rule, it reduces the nominal policy rate and thereby the net interest margin, credit and output. At the same time, despite the large drop in output, the drop in inflation is very small, because tighter credit rationing partly offsets the reduction in user costs and wages. The more elastic is credit, the larger is the decrease in output and the smaller the decrease in inflation.

The bottom half of Figure 8 compares the ZLBD-constrained and unconstrained economies. Because the shock to consumption preferences is identical, the consumption responses of the two economies are similar, but otherwise the results for the unconstrained economy are very different. The effect of the financial friction 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 user costs and wages, and leads to a larger drop in the nominal and real policy rate. But because this is accompanied by a similar drop in the deposit rate, the effect on the net interest margin is much smaller, and merely reflects the lower marginal cost of lending after the exogenous 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.

In ZLBD-constrained economies, the output effects of Taylor-type changes in monetary policy rates in response to changes in inflation are therefore the opposite, *ceteris paribus*, of unconstrained economies. For example, while a reduction in the policy rate in response to a contractionary demand shock makes the shock less contractionary in an unconstrained economy, it makes it more contractionary in a ZLBD-constrained economy.

5.3.2. Alternative Monetary Policy Rules

The simulations in Figures 6 and 8 show that in a ZLBD-constrained economy systematic responses of the nominal policy rate to inflation have much larger output effects than in an unconstrained economy. An aggressive response to inflation is therefore much less helpful in stabilizing output. The reason is that monetary policy affects the real economy not only through the real interest rate channel but also through the financing channel. This raises two questions: First, would a less aggressive response to inflation help to dampen output fluctuations? And second, could a systematic response that takes the financing channel into account stabilize the real economy more effectively?

To answer the first question we have repeated the shock of Figure 8 while varying the inflation gap feedback coefficient m_π from 3 to 2 to 1.1. We find that the only effect is a smaller decline in the real policy rate and thus a slightly larger decline in output. This does not support a policy of responding less strongly to inflation. Figure 9 instead varies the loans gap feedback coefficient m_ℓ from 0 to 2 to 8. With a positive m_ℓ, when banks reduce credit due to insufficient net interest margins, this *ceteris paribus* triggers a systematic (rules-based) monetary easing, thereby generating an inflationary response that increases net interest margins. This significantly reduces credit rationing while permitting a much larger drop in the real policy rate due to higher inflation. This combination implies a much shallower contraction, specifically a smaller drop in consumption and an increase rather than a drop in investment. Therefore, when policymakers are aware that credit has become an important constraint on real activity, responding aggressively to reductions in credit by way of monetary easing has sizeable beneficial effects. But even a symmetric response to positive as well as negative loans gaps is beneficial, because at a suboptimal steady state such as the ZLBD the benefits of dampening a contraction are greater than the costs of dampening an expansion.

The bottom half of Figure 9 studies the determinacy properties of the monetary policy rule (21) as a function of the feedback coefficients m_π and m_ℓ. In the unconstrained economy, the Taylor principle $m_\pi > 1$ holds at $m_\ell = 0$. A slightly weaker inflation response becomes possible as m_ℓ grows, due to the presence of the financial component of marginal cost $1/\left(1 - i_t + i_t^d\right)$. But with m_π even slightly above 1, any m_ℓ is compatible with determinacy. In the ZLBD-constrained economy, the loans gap becomes much more critical for determinacy, with $m_\ell \geq 0$ required except for the possibility of slightly negative m_ℓ at extremely high inflation gap coefficients. More importantly, as long as $m_\ell \geq 0$ the inflation gap coefficient can become smaller than one, with only a very weak requirement on the overall response to inflation of $m_\pi > 0$. 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 overall inflation.

6. Conclusions

We develop and study a New Keynesian DSGE model where the key macroeconomic function of banks is to provide a payment system that must be used for every economic exchange, and where only banks can create the deposits that must be used for every exchange. Banks create deposits through the disbursement of loans, subject to an increasing marginal cost of lending that, in our favored interpretation, represents limited processing capacity and limited balance sheet capacity. In this model, bank lending plays a critical role in the determination of aggregate economic activity, because additional loans create additional deposits, additional deposits facilitate additional economic exchange, and additional economic exchange facilitates additional economic activity. The aggregate purchasing power available to non-banks is therefore not limited to their internal cash flow, generated by income-earning activities, but can be augmented by external cash flow, generated by new bank loans. This in turn mobilizes additional resources and thereby creates additional income, especially in financially constrained economies with under-utilized resources. However, banks' willingness to perform this function depends on their ability to earn an adequate net interest margin on their lending. The net interest margin is the difference between the loan rate and deposit rate, and in our simple model where lending margins are absent, the difference between the policy rate and deposit rate.

This implies that any friction that limits the net interest margin that banks are able to earn, and that thereby prevents banks from elastically supplying deposits, can have sizeable consequences for real economic activity. The friction that we study in this paper is the zero lower bound on deposit rates (ZLBD), in an economy where the policy rate is already so low that the net interest margin is compressed, and credit is lower than it would be in a world where deposit rates have further scope to adjust. In such a ZLBD-constrained economy, banks' loan supply function becomes an exogenous credit rationing constraint for borrowers, and the tightness of that constraint depends on the semi-elasticity of credit supply with respect to the net interest margin. We estimate that semi-elasticity from US data, and find it to be high. Specifically, a 1 percentage point (roughly 30% relative to the pre-GFC period) reduction in the net interest margin leads banks to reduce lending by 10% in an unconstrained economy, and by 15% in a ZLBD-constrained economy.

We show with this semi-elasticity, or even with significantly lower semi-elasticities, the output-inflation trade-off at the ZLBD is dominated by a very flat steady state Phillips curve. The reason is that lower inflation is associated with a lower nominal policy rate, which in turn causes a drop in the net interest margin. This has a large negative effect on credit and therefore on output, while at the same time acting as a cost-push shock that limits the overall drop in prices. This result allows us to establish the following conclusions for ZLBD-constrained economies. First, changes in policy rates have far larger output effects and far smaller inflation effects than in unconstrained economies. Over the medium term, even a small permanent increase in the nominal policy rate due to higher steady state inflation facilitates a large permanent expansion in credit and output. The current efforts of central banks to return inflation rates to their medium term targets are therefore extremely important. In the meantime, even a modest temporary monetary easing facilitates a sizeable temporary expansion in credit and output at a modest cost in terms of inflation. Second, the *ceteris paribus* output effects of Taylor-type changes in the policy rate in response to changes in inflation are the opposite of unconstrained economies. For example, a reduction in the policy rate in response to lower inflation following a contractionary demand shock makes the shock more rather than less contractionary. This suggests that central banks should exercise great caution in pushing policy rates into negative territory, even temporarily. Third, modifications of monetary policy rules that allow for monetary easing in response to reductions in credit, while maintaining a Taylor-type response to inflation, make monetary policy far more effective at stabilizing output, consumption and hours worked. This suggests that central banks should not only pay attention to the interactions of their rate setting decisions with inflation and output, but also with banks' net interest margins and thereby with credit conditions.

All of these conclusions have become even more timely and policy-relevant in the post-COVID-19 environment. The motivation behind some large policy packages that have already been passed has in large part been to help overcome the reluctance of banks to lend under the present severe economic conditions. For a proper assessment of the likely consequences of such packages, it is essential that all transmission channels of bank lending are considered. So far comparatively little attention has been paid to the bank financing channel, the ability and willingness of banks to create macroeconomically essential purchasing power when faced with low net interest margins. The present paper is an attempt to advance the debate in this direction.

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Table 1. Estimation Results (2SLS)

First-Stage Regression

$cispreadnet_t$	**Coefficient**	**t**	**P>$\|t\|$**	**95% Confidence Interval**
Δgdp^*_{t-1}	0.402	3.13	0	(0.146, 0.659)
$liquidity^*_{t-1}$	-0.219	-9.01	0	(-0.267,-0.170)
$supply_{t-1}$	-0.003	-0.82	0.42	(-0.0120,0.004)
$DEMAND^*_{t-4}$	0.022	8.06	0	(0.017,0.028)
$cons*$	9.166	10.51	0	(7.43,10.905)

Second-Stage Regression

$Lnrealciloan_t$	**Coefficient**	**t**	**P>$\|t\|$**	**95% Confidence Interval**
$cispreadnet^*_t$	0.108	4.94	0	(0.064, 0.152)
Δgdp^*_{t-1}	-0.075	-3.1	0	(-0.123, -0..026)
$liquidity^*_{t-1}$	0.056	8.76	0	(0.043, 0.069)
$supply^*_{t-1}$	0.003	5.03	0	(0.002, 0.004)
$cons*$	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 2. Model Calibration

Description	**Calibration Target**	**Parameter**	**ZLBD-Constrained Value**	**Unconstrained Value**
Real Policy Rate (p.a.)	2%	β	0.9950	0.9950
Nominal Policy Rate (p.a.)	2% / 4%	$\bar{\pi}$	1.0000	1.0050
Nominal Deposit Rate (p.a.)	0% / 2%	κ	0.0100	0.0050
Credit Spread Semi-Elasticity	10	ξ	0.4020	0.2015
Intertemporal El. of Substitution		ϵ	0.5	0.5
Consumption Habit		v	0.75	0.75
Labor Supply Elasticity		ζ	1.0	1.0
Labor Supply	1	χ	0.2353	0.2249
Labor Income Share	60%	α	0.3333	0.3367
Investment/GDP	20%	δ	0.0102	0.0098
Government Spending/GDP	18%	$\bar{g}$	0.6051	0.8324
Government Debt/GDP	100%	$\bar{\tau}_L$	0.4327	0.3338
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

Figure 1: US Inflation Rate and Unemployment Rate during Recessions

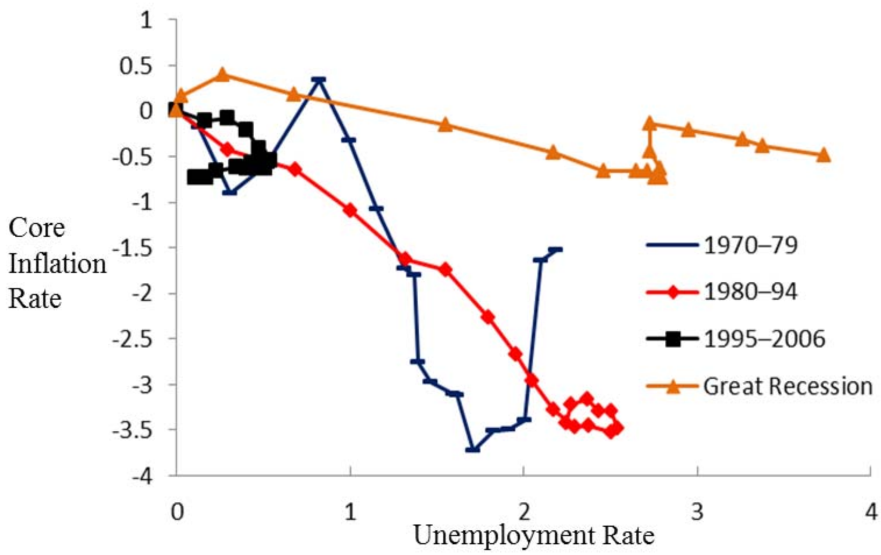


Figure 2: US Commercial and Industrial Loan Spreads

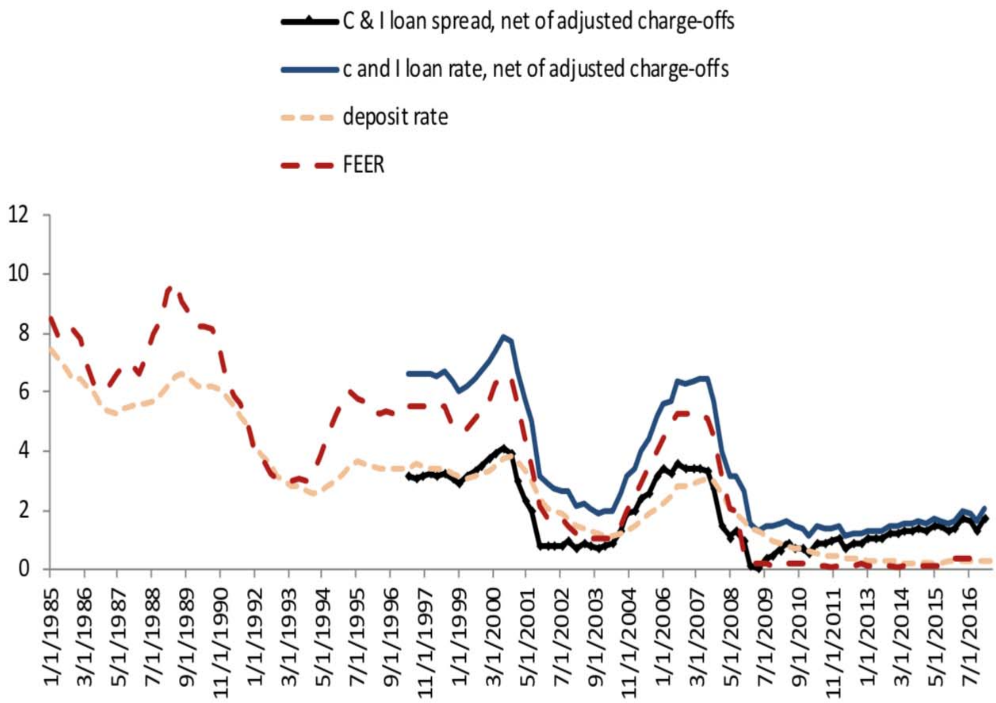


Figure 3: Timeline of Intra-Period Cash Flows

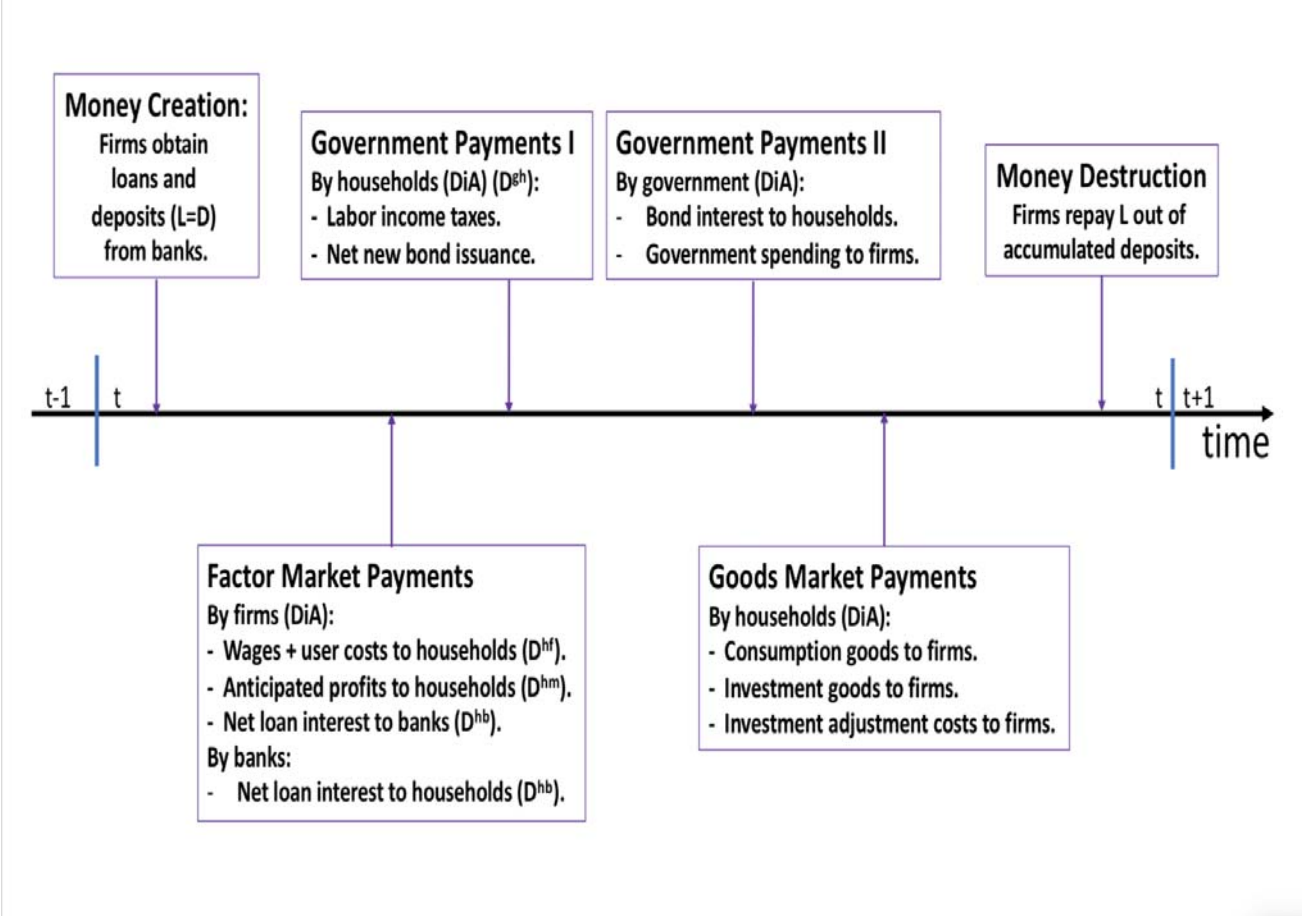


Figure 4: The Payment Cycle

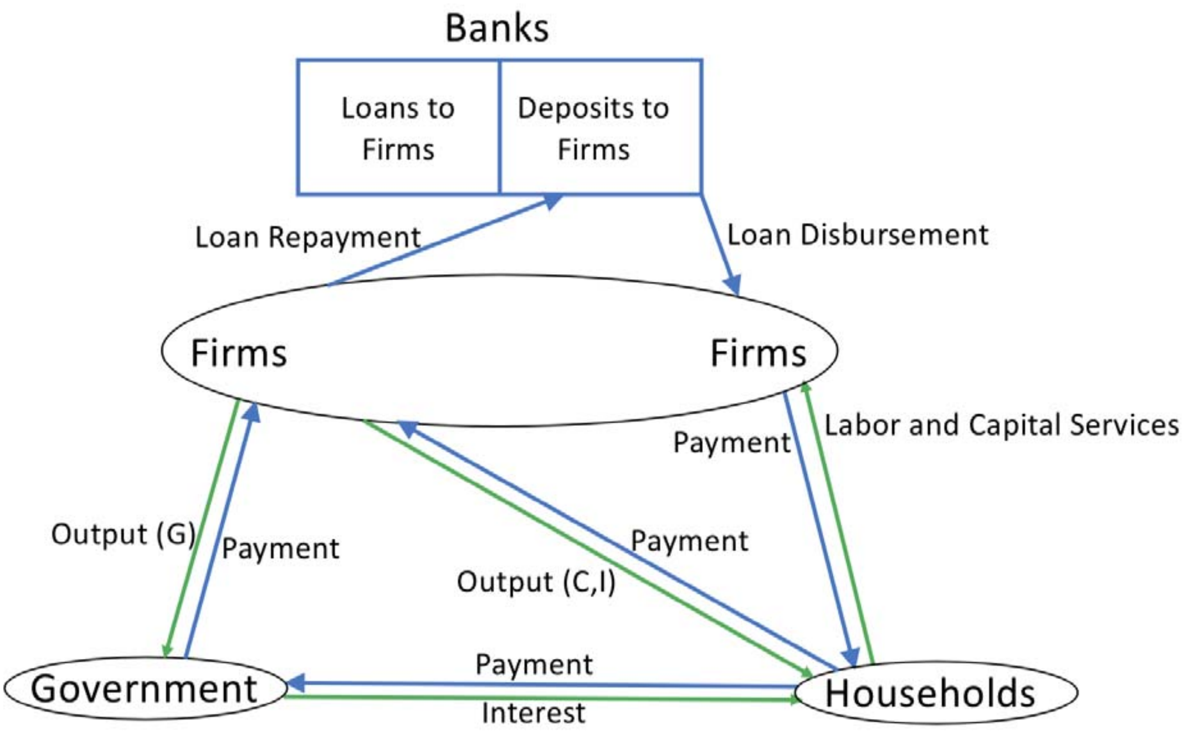
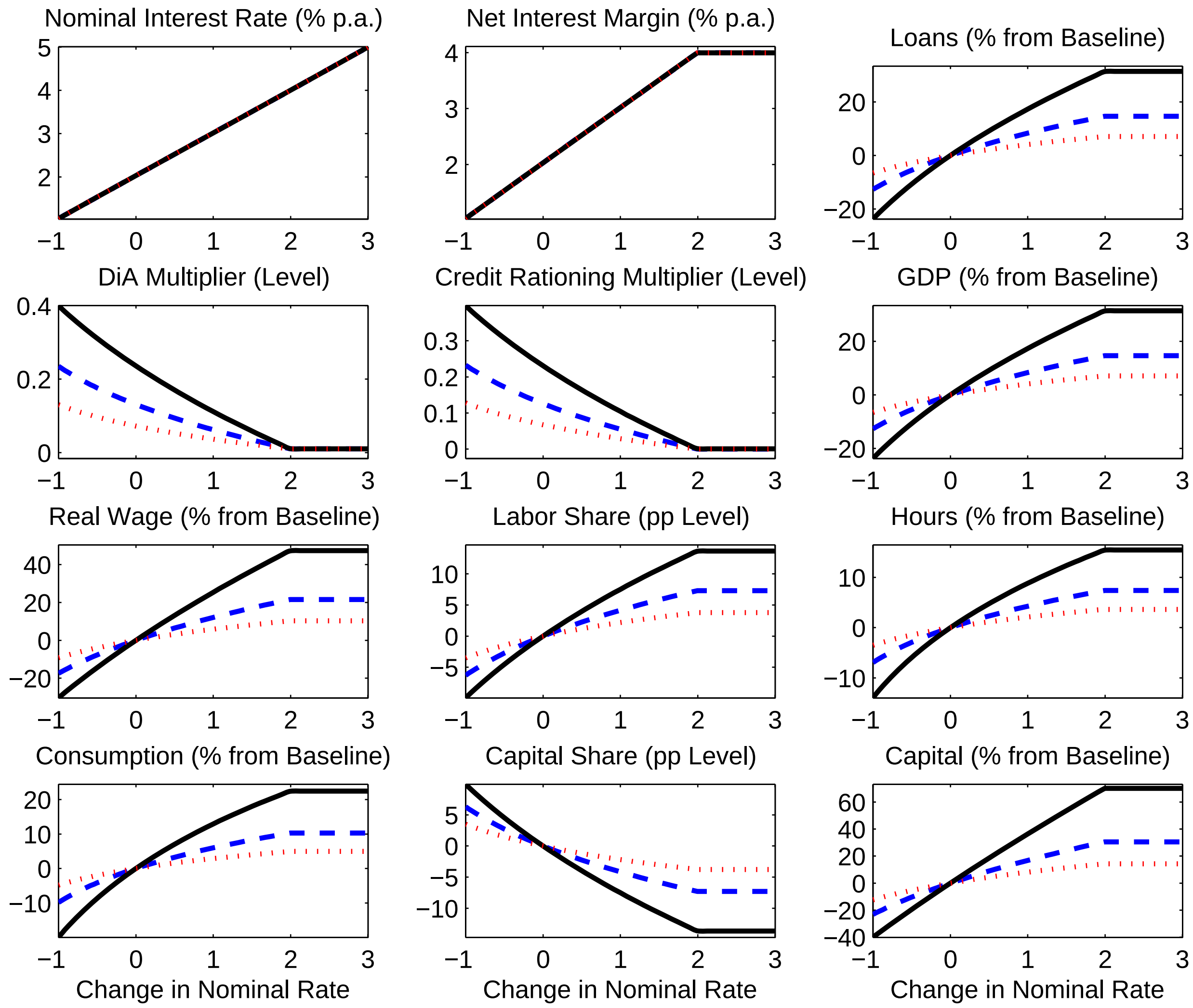
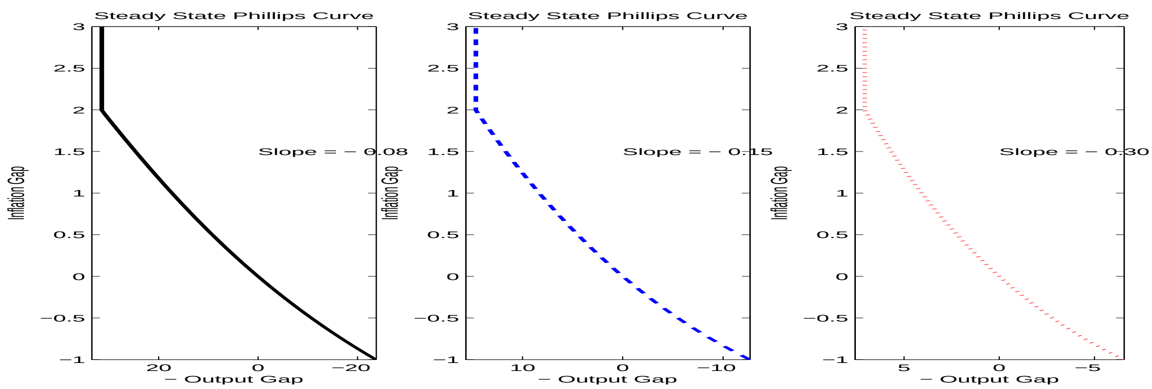


Figure 5: Effects of Changing the Steady State Policy Rate at the ZLBD
under Different Credit Supply Semi-Elasticities

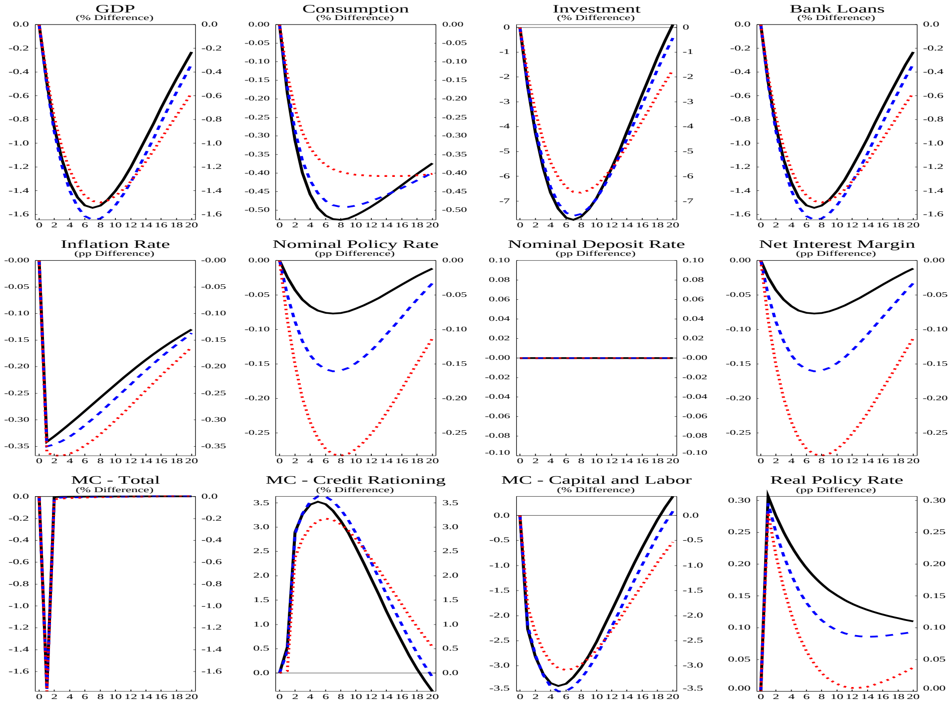


Endogenous Variables as a Function of the Nominal Policy Rate

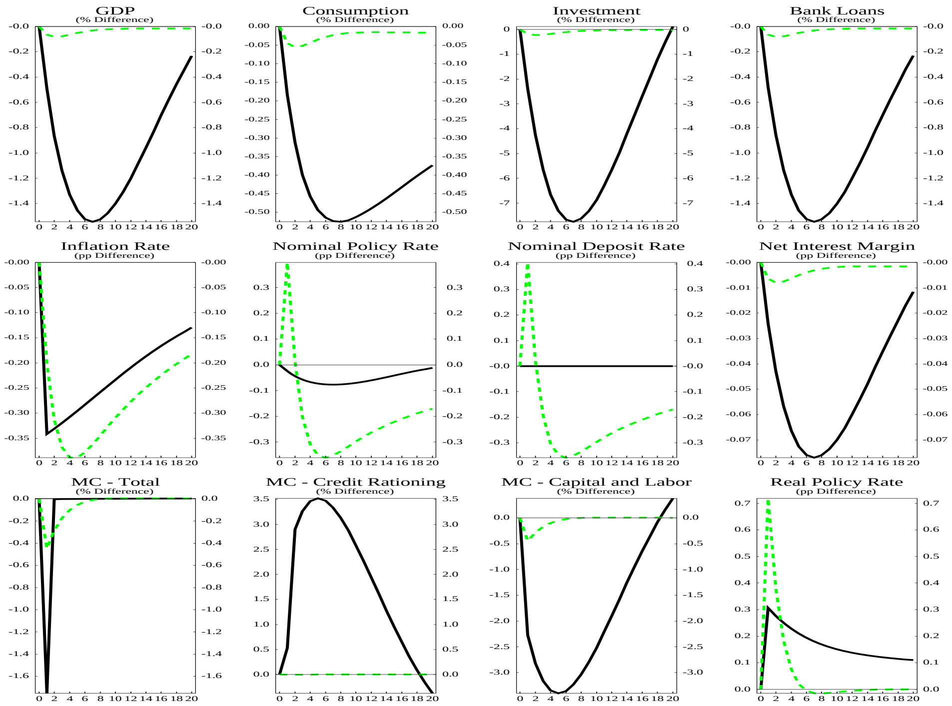


Steady State Phillips Curves
(Credit Supply Semi-Elasticities: Black solid = 10, blue dashed = 5, red dotted = 2.5)

Figure 6: Contractionary Monetary Policy Shock



ZLBD-Constrained Economy
(Credit Supply Semi-Elasticities: Black solid = 10, blue dashed = 5, red dotted = 2.5)



ZLB-Constrained (black solid) versus Unconstrained (green dashed) Economy
(Credit Supply Semi-Elasticity = 10)

Figure 7: Phillips Curves for Monetary Policy Shocks and Different Model Versions

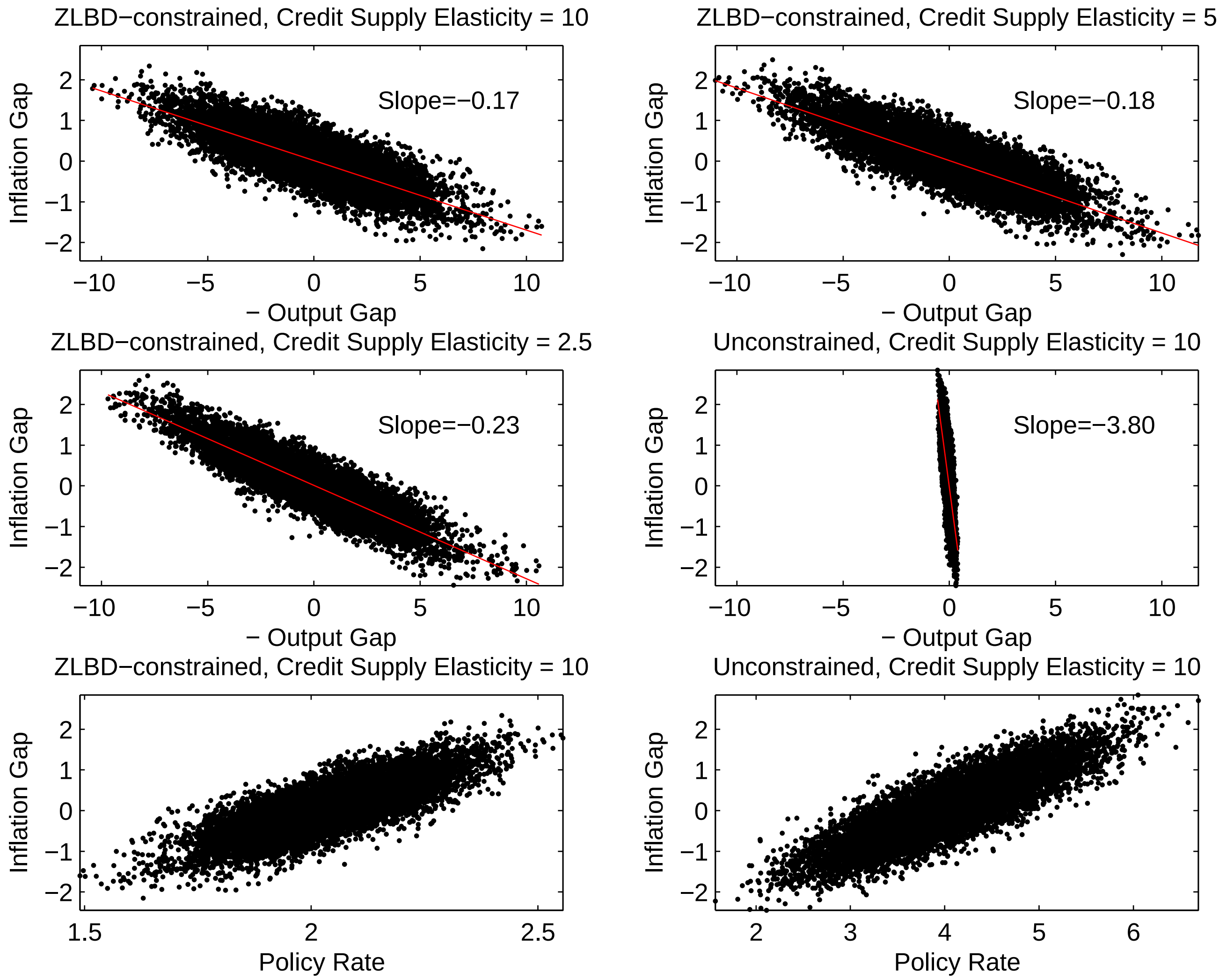
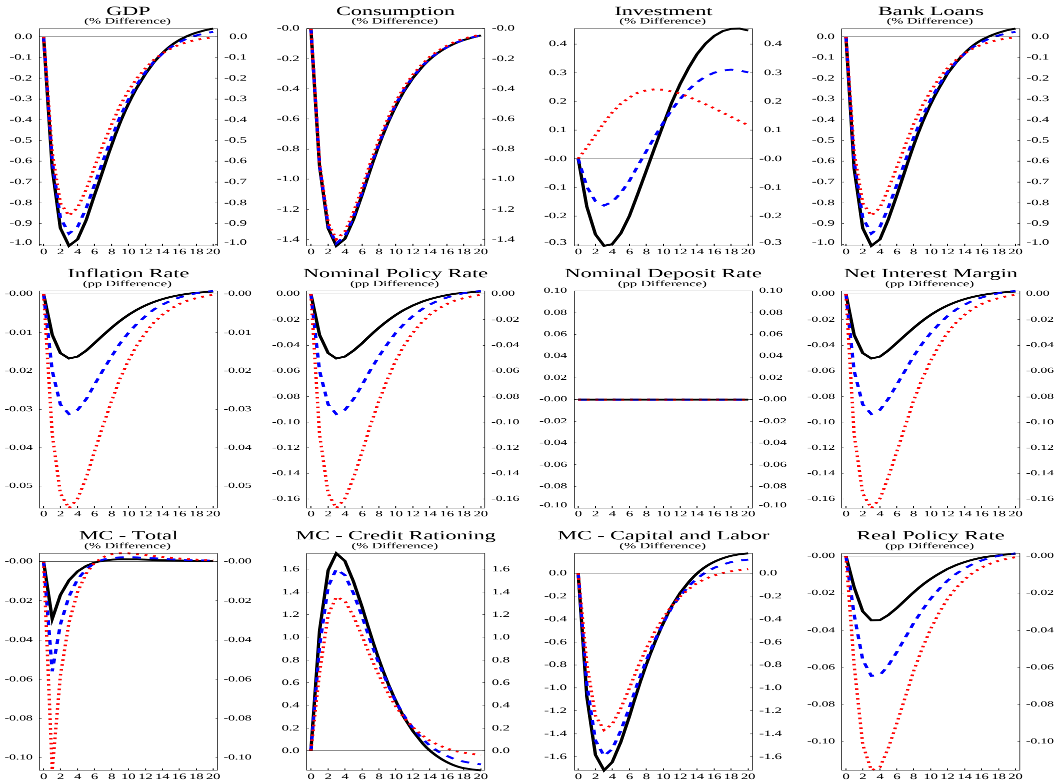
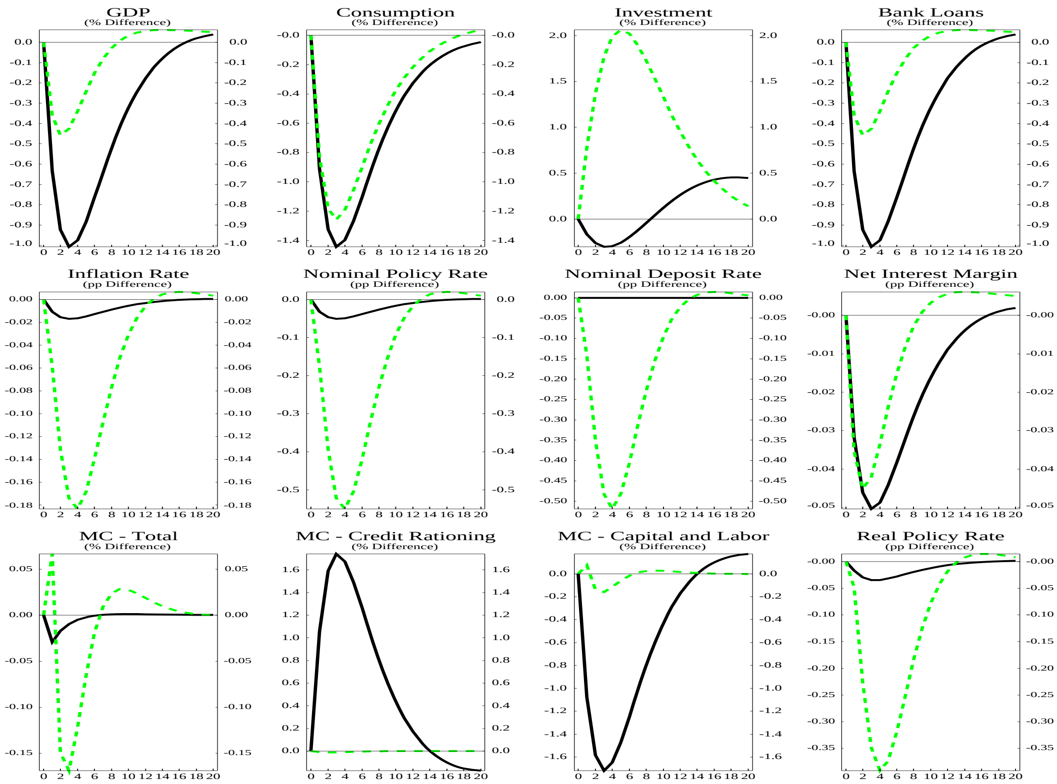


Figure 8: Contractionary Consumption Demand Shock



ZLBD-Constrained Economy

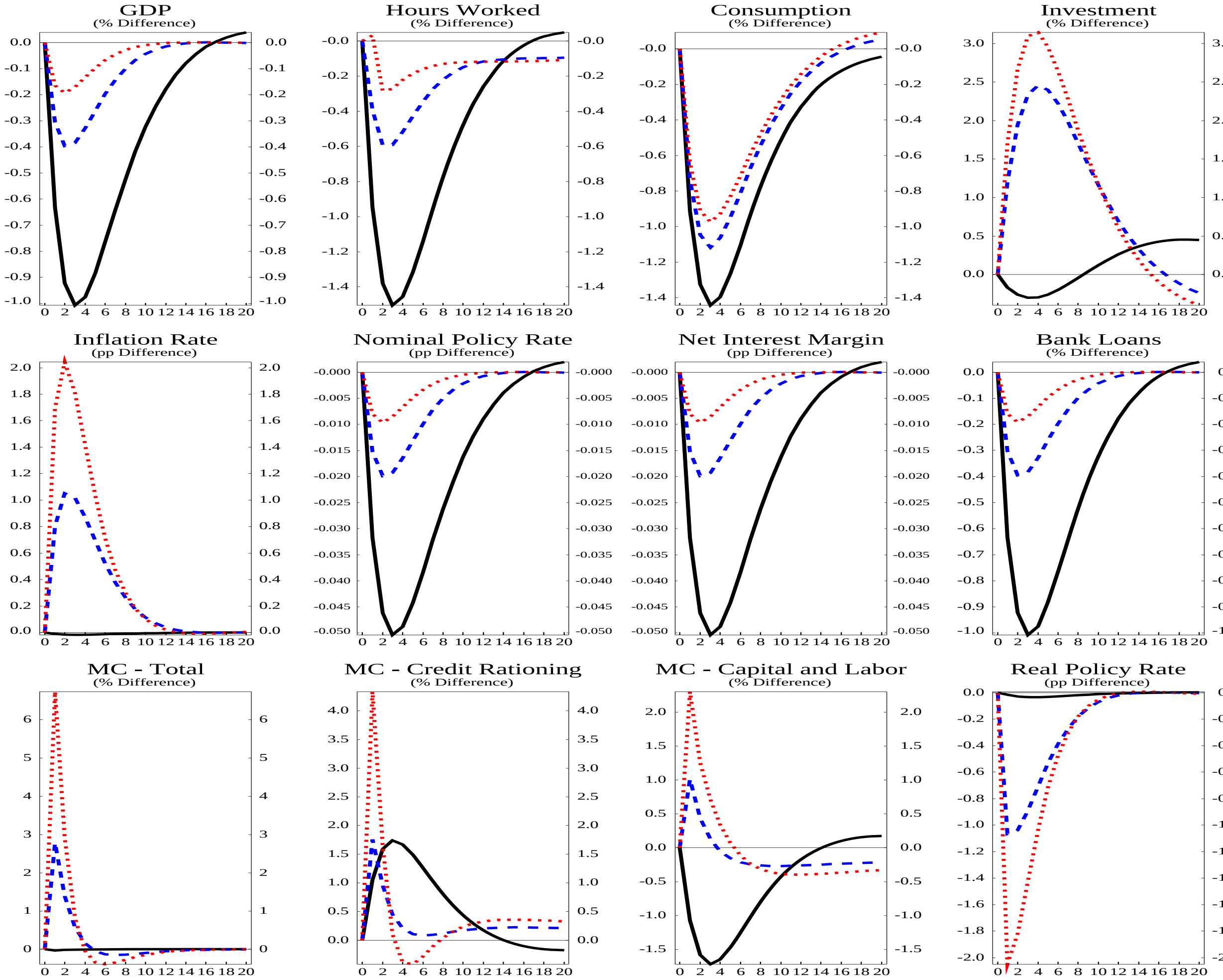
(Credit Supply Semi-Elasticities: Black solid = 10, blue dashed = 5, red dotted = 2.5)



ZLB-Constrained (solid) versus Unconstrained (dashed) Economy

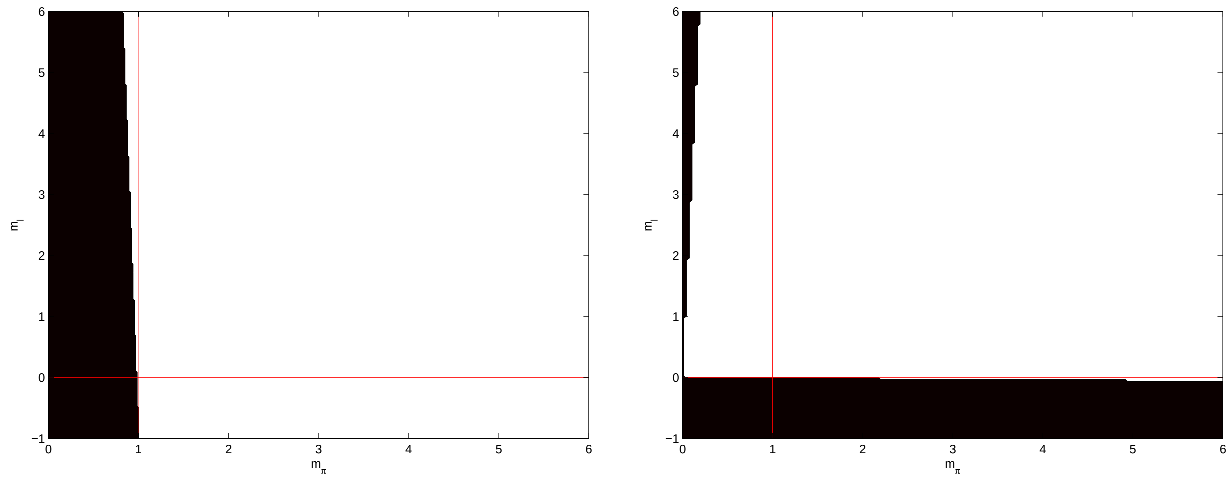
(Credit Supply Semi-Elasticity = 10)

Figure 9: Contractionary Consumption Demand Shock with Different Policy Rules



ZLBD-Constrained Economy

(Credit Feedback Parameter : Black solid = 0, blue dashed = 2, red dotted = 8)



Unconstrained Economy ($\varepsilon = 10$) ZLBD-Constrained Economy ($\varepsilon = 10$)

Determinacy Regions (white = BK-stable)