Balance Sheet Policies and Financial Stability

Preliminary Draft

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1 Introduction

The policy arsenal of central banks has undergone a noticeable expansion in recent years. Policymakers are no longer limited to one instrument of policy creation; conventionally embodied by the policy rate. Balance sheets of monetary authorities are playing an increasingly important role in policy formulation, as recently emphasised by Bernanke (2011). Policies that increase the size and composition of central bank balance sheets are now used in conjunction with interest rate policy to combat, simultaneously, price- and financial instability[1].

Central banks have traditionally only considered the balance sheet in its capacity to steer the overnight rate towards the policy target. The objective of this paper is to determine in what capacity central bank lending can be used to prevent financial instability. Our hypothesis is most similar to that of Goodhart et al. (2011), who consider the potential impact of monetary injections (as the dual of the interest rate) on financial stability, but we differ on a few specifics.

First, this paper is set in a dynamic general equilibrium setting. This approach allows the researcher to consider the dynamics of the economy, as opposed to a comparative static setting. The model presented here is similar to the approach adopted in de Walque et al. (2010). However, we embed the crucial properties of their Real Business Cycle (RBC) model into a New-Keynesian setting with price and wage rigidities; which allows for a richer understanding of the implications of monetary policy.

Second, we endeavour to provide a more realistic presentation of central bank lending. In Goodhart et al. (2011) the monetary base is mapped one-to-one on the interest rate, which is not an accurate representation of modern central bank practice. Two important contributions to the literature that also look at the impact of monetary injections on financial stability are de Walque et al. (2010) and Dib (2010a). However, in both these papers, the way in which their monetary authority is structured is ad hoc, with direct money injections from the central bank to the commercial (merchant/lending) bank. This paper differs in that we adopt the collateralised central bank lending approach of Schabert (2015).

The paper is structured as follows. First an overview of the related literature, ranging from issues pertaining to financial frictions in DSGE models and also methods for employing central bank lending in mainstream models. Second, the model is presented, with integration of the mechanism proposed by Schabert (2015) in the banking and public sector. The model is kept as simple as possible, abstracting from financial frictions in the demand side of the credit

[1] Macroprudential policy measures are also being used in varying degrees by central banks. Existing on occasion as part of the monetary policy space and at other times separated by independence from monetary authorities

market. Third, a discussion on the results from the impulse response functions following an increase in the policy rate (monetary tightening). Finally, the last section concludes.

2 Literature Review

The two decades preceding the Great Recession were marked by an unprecedented consensus on the "intellectual and institutional framework for monetary policy" (Bernanke, 2011). At the heart of the consensus is the dynamic general equilibrium framework, which was pioneered by Leeper and Sims (1994) and Schorfheide (2000). It was then further propelled into the mainstream by the seminal contributions of, amongst others, Smets and Wouters (2003, 2007) and Christiano et al. (2005). This macroeconometric modelling paradigm has been universally implemented by central banks; who were able to successfully utilise the models to better understand the consequences of policy actions and thereby achieve macroeconomic stability. However, these models were not equipped to forestall financial market failure.

Economics, as a discipline, advocates the use of theoretical frameworks that often ignore knotty real world frictions in order to remain tractable and computationally feasible (de Walque et al., 2010). Theorists are tasked with making assumptions that reduce complex real world interactions into digestible mathematical equations. Some of these assumptions have come under fire. In particular, the idea that financial markets are perfect and complete; with the implication that financial shocks are irrelevant to real economic outcomes (Roger and Vlcek, 2012). There was a commonly held belief that finance, in first approximation, was irrelevant to business cycle movements (Woodford, 2003). However, owing to recent event it has been acknowledged that the financial crisis originated from a collapse of financial intermediation, which has cemented the idea that credit market frictions have real implications (Ahn and Tsomocos, 2013). The next section discusses several approaches to introducing endogenous financial frictions into the existing New-Keynesian framework.

2.1 Financial Frictions in DSGE Models

Prudent monetary policy, as defined in pre-crisis policy models, is primarily centered on issues pertaining to price stability. Financial stability is often considered an incidental byproduct, with financial sectors curiously absent from the majority of mainstream models (Borio, 2014). The dearth of financial markets in core models is contrasted by a rich vein of research in the periphery that accentuates the role of financial market conditions in propagating cyclical fluctuations. Fisher (1933) and Keynes (1936) are among the earliest to develop an alternative narrative that emphasises that impaired credit markets[2] could substantially contribute to a decline in the real economy[3]. More recently, in the postwar period, these points have been brought to the fore by the contributions of Minsky (1957, 1982) and Kindleberger (2000). Their argument is directly at odds with the assumption of perfectly competitive financial markets; which was popularised by Modigliani and Miller (1958) in their capital structure irrelevance proposition[4].

2.1.1 Demand Side Frictions

In perfectly competitive financial markets there are no frictions that limit access to credit; allowing no insight into scenarios where agents are credit constrained. Financial frictions were introduced into DSGE models to address this limitation. Pioneering contributions to the literature, to include information asymmetries and non-convex transaction costs, were forwarded by Bernanke and Gertler (1989) and Kiyotaki and Moore (1997). Both of these veins of research proposed alterations to the consensus approach; introducing frictions in the *demand side* of the credit market, where banks act exclusively as intermediaries between households and firms. Financial market conditions in these models serve to frame a more complete narrative of the forces that propagate economic growth.

2.1.1.1 External Finance Premium Bernanke and Gertler (1989) were the first to successfully consolidate the financial accelerator mechanism and general equilibrium framework. Inclusion of a financial accelerator is significant as it allows endogenous credit market developments to act both as a source of business cycle fluctuations and as amplification device. Bernanke and Gertler (1989) postulate that, in the light of tightened financial market conditions, temporary credit shocks could have a strong and persistent effect on the business cycle. In order to sufficiently constrain credit markets they integrate the costly state verification framework proposed by Townsend (1979) into a general equilibrium environment.

Costly state verification entails the existence of information asymmetries that obscure the borrower-lender relationship. In the model proposed by Bernanke and Gertler (1989) a newly proposed agent, namely the entrepreneur, plays a central role. One of the noteworthy functions of this entrepreneur is it's ability to produce capital from consumption goods. In addition, entrepreneurs invest out of their own wealth as well as taking loans from households.

[2] Examples of impaired credit conditions include, "sharp increases in insolvencies and bankruptcies, rising real debt burdens, collapsing credit prices, and bank failures" (Bernanke et al., 1998)

[3] Theories were developed owing to the events surrounding the Great Depression

[4] This assumption asserts that the capital structure of banks is largely irrelevant and indeterminate for lending decisions and thereby real economic outcomes.

Entrepreneur net worth is subject to a idiosyncratic shock, where the outcome of the shock is directly observed by the entrepreneur but not the originator of the loan. Lenders would ideally want to know whether entrepreneurs will be able to repay their debt. However, lenders are forced to pay a monitoring cost if they wish to gain information as to solvency of the entrepreneur. Therefore, borrowing is limited because monitoring a loan applicant is costly (Brzoza-Brzezina et al., 2011). Efficiency in the process of matching potential borrowers and lenders is reduced (Bernanke et al., 1998).

In this framework, borrowers face a risk premium that is decreasing in their net worth (Roger and Vlcek, 2012). Standard debt contract includes a premium on the interest rate to cover the cost of default in case of negative wealth shocks (Christiano et al., 2010). An endogenous wedge between lending rate and the risk free rate is created and is called the **external finance premium** (Brzoza-Brzezina et al., 2011). In other words, the price of loans is directly affected in this economy. Decrease in price negatively affects the net worth of the entrepreneur and increases the financial friction. The result is lower levels of investment in the next period, coupled by lower net worth. This feedback mechanism results in a strong persistence as the result of tight financial market conditions.

This model setup was further improved upon by Carlstrom and Fuerst (1997), who incorporated the dynamics into a New Keynesian DSGE model. Bernanke et al. (1998) added nonlinear capital adjustment costs, to become the workhorse financial accelerator model that is used in many central banks around the world[5]. Important contributions that built on this structure were made by Christiano et al. (2003, 2008) and De Fiore and Uhlig (2005). More recently, Christiano et al. (2014) contributed to the existing paradigm by introduction of "idiosyncratic uncertainty in the allocation of capital". Entrepreneurs face uncertainty in the process of converting capital into effective capital; where the magnitude of this uncertainty is modelled as 'risk'.

2.1.1.2 Collateral Constraint The financial accelerator proposed by Kiyotaki and Moore (1997) operates by a different friction than the external finance premium. In this model the agents differ in terms of their time preference. As dictated by their preference, agents identify as either a lender or borrower. Intermediation exists between these two explicit groups. Borrowers differ in this market and are required, by the financial intermediary, to provide collateral for loans. Whereas the friction in Bernanke and Gertler (1989) was based in asymmetric information and affected the price of loans, this friction functions on the basis of incomplete contracts and directly impacts on the specific quantity of loans (Kiyotaki and

[5]Nonlinear capital adjustment costs added another amplification effect to the model

Moore, 1997).

Owing to a criticism by Kocherlakota (2000) on the ability of credit constraint frameworks to generate empirically valid amplification of shocks, several important attempts were made to develop a more realistic setting. Cooley et al. (2004) stands out as one of the early attempts at providing a more quantitatively accurate representation. This was achieved by not focusing exclusively on collateralised debt as the primary form of financing for the firm, but rather including state-contingent financial contracts. Iacoviello (2005) combined elements of the financial accelerator model developed by Bernanke et al. (1998) and the collateral constraint as in Kiyotaki and Moore (1997). The original contribution of this model is the fact that firms need to provide real estate as collateral; which he motivates both on practical and substantive grounds.

Financial frictions were initially introduced almost exclusively on the demand side of credit markets, with an explicit focus on the balance sheets of non-financial borrowers (Meh and Moran, 2010). Unfortunately these models neglect the role of financial intermediaries, treating them as a veil (Gertler and Karadi, 2011). Recent events surrounding the financial crisis highlighted the importance of financial shocks originating in the banking sector as a source of business cycle fluctuations (Dib, 2010a). This has resulted in a concerted effort to develop models that explore disruptions in the supply of credit in financial markets (Falagiarda and Saia, 2013). In a liquidity crisis financial intermediaries become credit constrained and this friction reveals how shocks in the financial economy could have implications for the real economy (de Walque et al., 2010).

2.1.2 Supply Side Frictions

The Great Recession has highlighted the central role of financial shocks in driving macroeconomic indicators in the real economy (Quadrini, 2011). Researchers are now tasked with the advancement of models that better incorporate frictions on the supply side of credit markets; specifically fostering models with persuasive, well-founded, banking sectors. Investigation has revealed several components that are believed to be crucial in capturing the essence of a sophisticated banking sector. Some of the particular characteristics that need to be incorporated are related to bank capital, interest rate spreads, interbank markets and the possibility of default. We will now briefly touch on some of these issues[6].

[6] These themes do not provide a comprehensive account of all the important issues related to developing a functioning banking sector. Some papers will also belong to more than one specific theme

2.1.2.1 Banking Sectors and Bank Capital Several authors have endeavoured to construct realistic banking sectors. The first wave of models had the specific goal of approximating the bank capital channel. Previously it was thought that, in line with the assumptions found in Modigliani and Miller (1958), the structure of bank capital is unimportant to lending decisions. However, this is the antithesis of this specific breed of supply side models, which explicitly states that bank capital affects bank lending and thereby real economic activity (Roger and Vlcek, 2012). There has been a large influx of these types of models, with many central banks adopting them as the new workhorse. The reason being that policymakers wish to incorporate the recent changes to Basel III regulatory requirements. Generally, these model still follow either the collateral constraint or financial accelerator framework[7]; with the addition of costly bank capital.

Early incarnation of this type of model that try and develop the bank capital channel are that of Markovic (2006), Van den Heuvel (2008) and Angeloni et al. (2009). The work of Markovic (2006)[8] was particularly influential. The most important contribution in their paper, which builds on the financial accelerator framework, is the introduction of a banking sector where banks face adjustment costs in capital accumulation. Asymmetric information between bank and shareholders are the source of the adjustment cost, as shareholders need to incur search costs before investing (Markovic, 2006).

More recent contributions to address issues of bank capital include Meh and Moran (2010) and Dib (2010a,b)[9]. Meh and Moran (2010) introduce the double moral hazard framework, as originally proposed in Holmstrom and Tirole (1997), into a general equilibrium setting. In this model, the interactions of bank capital and entrepreneurial net worth have implications for economic activity. Dib (2010a,b) also develops a model with an important role for bank capital; specifically looking at the ability of bank capital to satisfy capital requirements as a prerequisite for banks to issue loans to entrepreneurs. Similarly, regulatory requirements are the motive for costly bank capital in models presented by Gerali et al. (2010) and Dellas et al. (2010)[10].

2.1.2.2 Interest Rate Spreads (Need to expand this section.) The importance of including a time varying interest rate spread is highlighted in the work of Cúrdia and Woodford (2009, 2010). They include an ad hoc friction in financial intermediation that gives rise to spread between loan and policy rate.

[7] Sometimes even a hybrid of the two
[8] A model developed at the Bank of England
[9] Both models were developed for use by the Bank of Canada
[10] Used by the Bank of Italy and Bank of France, respectively

2.1.2.3 Interbank Markets and Default Failure of interbank markets are increasingly viewed as one of the most important contributing factors to the extent of the damage caused by the financial crisis. In order to address these problems, researchers have to develop an active banking sector where banks are allowed to interact and possibly default. Relatively few papers have incorporated banking sectors and default (Roger and Vlcek, 2012). Perhaps the first model to include an explicit banking sector is that of Gerali et al. (2010). Their model includes a constraint on bank balance sheets, which affects bank capital, profit and thereby the supply of loans in the economy. Unfortunately, there is no interaction among wholesale banks in this model. Gertler and Kiyotaki (2010) take another approach to the interbank market. Financial institutions in this setup are exposed to liquidity shocks that distinguish them from each other. These idiosyncratic shocks can potentially disrupt the intermediation process and thereby real economic activity. The biggest shortcoming of this model is that financial institutions resemble a homogenous intermediary in aggregate. In other words, the banking sector does not consist of heterogenous agents and therefore can't truly represent an interbank market.

A relatively new stream of research, that was built on the ideas of Goodhart et al. (2006a)[11], provides advances in the development of interbank markets and default. One of the most important contributions of their body of work has been the inclusion of a heterogenous and endogenous banking sector. They abstract from the representative agent approach in modelling the banking system. This allows the interaction of banks on the interbank market and thereby the possibility to model the reaction of commercial banks to certain shocks. Failure of banks, or endogenous default as developed by Shubik and Wilson (1977) and Dubey et al. (2005), is one of the primary features of this model. Failure is a function of the risk preference of banks in this system, with the riskiest banks assigned the highest probability of default. These failures are not isolated events in this model and have system wide implications for the survival of other banks.

Several authors have adopted this framework to explore various macroeconomic issues. Some of the important articles in this tradition are those of Goodhart et al. (2009), de Walque et al. (2010), Dib (2010a,b), Hilberg and Hollmayr (2011), Martinez and Tsomocos (2011), Carrera and Vega (2012) and Ahn and Tsomocos (2013). This paper most closely resembles the work of de Walque et al. (2010). The contribution of this paper is in the addition of a more realistic representation of central bank lending.

[11] This article is the culmination of years of research and several other articles are linked in the model's construction (see, for example, Aspachs et al. (2005); Tsomocos and Zicchino (2005); Aspachs et al. (2006); Goodhart and Tsomocos (2006)).

2.2 Central Bank Lending as Prudential Policy Tool

The categorisation of central bank policies as specified in Cúrdia and Woodford (2011) and Goodfriend (2011) is used as a basis for the dimensions of policy presented in this paper. Three distinct policy arms are identified. First, conventional *interest rate policy*; which entails the central bank's announcement of the official policy rate, as performed in most developed economies. This is what modern central banks routinely refer to as monetary policy (du Plessis, 2012). Second, *reserve-supply policy*, which is the choice of reserves in the system. In this paper, this policy dimension indicates changes in the size of the central bank's balance sheet. In particular, we intend it to translate to collateralised open market operations[12], where central bank liabilities (reserves) are traded in return for Treasury securities (Goodfriend, 2011). Third, *credit policy*, reflects direct supply of funds to the private sector in return for assets. This type of policy brings about changes in the composition of the banks balance sheet[13]. We are only concerned with the first two types of policy in this paper.

This paper primarily explores the effect of a change in the size of the balance sheet through central bank lending on financial stability[14]. This has been attempted by Goodhart et al. (2011), who incorporate the monetary base into their financial fragility framework and analyse its potential for use as prudential policy tool[15]. Their paper can be seen as a spiritual successor to William Poole's (1970) work on the instrument problem, in that they explore the effectiveness of both the monetary base and interest rates as tools of monetary policy.

Several papers have considered the optimal instrument choice in achieving price stability, but few have looked at the financial stability implications (Goodhart et al., 2011). The work of Poole (1970) signified a watershed in the discussion on the instrument problem, with the interest rate winning out as the most effective in achieving price stability. Owing to the criticism of Sargent and Wallace (1975) add forward looking features into their model and find, in contrast to Poole (1970), that money growth policies have an advantage over interest rate policies. This result has been contested by several authors, namely, McCallum (1981), Woodford (2003) and more recently by Atkeson et al. (2007) and Woodford (2008). We are, however, not interested in the instrument problem as it pertains to price stability.

In fact the question posed here is much simpler. We are interested in the resultant financial stability implications of changes in the size of the balance sheet of the central bank in the face

[12] This is what Goodfriend (2011) refers to as monetary policy

[13] One can think of the targeted asset purchases of mortgage backed securities after 2008 as an example of this type of policy

[14] There are several definitions of financial stability in the literature. We follow the approach of Goodhart et al. (2006a) in this paper

[15] Grauwe and Gros (2009) ask a similar question. They want to know if there is a trade-off between price and financial stability in the use of monetary policy tools

of interest rate policy. We don't consider which instrument is favoured to combat financial stability, but rather the impact of having a limited response in terms of changes in reserves to a change in the interest rate. The relationship between these variables has been expounded in the liquidity effect literature[16]. The haircut mechanism in the model is meant to decrease the sensitivity of reserve changes in light of a change in the policy rate.

3 The Model

This section will provide an account of the Dynamic Stochastic General Equilibrium (DSGE) model; which draws from the work of Smets and Wouters (2003, 2007), de Walque et al. (2010) and Schabert (2015). The model consists of **six sectors**. Both the **household** and **firm** sectors are closely related to the canonical New-Keynesian DSGE formulation of Smets and Wouters (2003, 2007)[17]. One significant difference is that the firm is allowed to default on his loans, as in de Walque et al. (2010). In addition, financial intermediation is included in the banking sector, which consists of two heterogenous banks, both with the option to default on loans (but not deposits).

The **deposit bank** receives deposits from households and provides loans to the interbank market. The **merchant bank** borrows from the interbank market and issues loans to firms. Merchant banks are also able to hold bonds issued by the government. These bonds serve as collateral in open market operations in the absence of unconventional monetary policy. The banking sector is similar to that of de Walque et al. (2010), but adds a form of collateralised central bank lending in the vein of Schabert (2015). The **government** can potentially purchase goods, raise lump-sum taxes and issue bonds. One could potentially extend this model to include short-term bonds and long-term bonds, with the long-term bonds modelled as perpetuities, as in Chen et al. (2012). The **Central Bank** sets the main refinancing rate according to a Taylor-type rule, supplies reserves in exchange for eligible collateral, and decides through the haircut mechanism on the size (and potentially composition) of its balance sheet.

[16] See the first chapter of the thesis for an overview on that literature

[17] In other words, the model combines advancements in real business cycle (RBC) methodology with sticky prices and wages gathered from the New Keynesian framework.

3.1 Households (h)

The household sector in this model closely follows Smets and Wouters (2003), which consists of a continuum of infinitely lived households, indexed by $j \in [0,1]$. Households maximise a lifetime utility function given by,

$$\max_{\{C_{j,t},N_{j,t},D_{j,t}\}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^h)^s \left[U^h_{j,t+s}\right] \tag{1}$$

where β^h is a discount factor and the utility function is separable in consumption and labour,

$$U^h_{j,t} = \frac{1}{1-\sigma_c}(C_{j,t} - hC_{j,t-1})^{1-\sigma_c} - \frac{1}{1+\sigma_n}(N_{j,t})^{1+\sigma_n} \tag{2}$$

Utility depends positively on consumption of goods $C_{j,t}$ (relative to an external habit variable $H_t = h \cdot C_{j,t-1}$) and negatively on labour supply $N_{j,t}$. Target for deposits is added in order to avoid indeterminacy, helps identify the steady state value for deposits. The coefficient of relative risk aversion is σ_c, which is also known as the inverse of the intertemporal elasticity of substitution and the Frisch elasticity of labour supply is σ_l. Households maximise utility subject to the flow budget constraint,

$$T_t + \frac{D_{j,t}}{R^d_t} + C_{j,t} = w_{j,t}N_{j,t} + \frac{D_{j,t-1}}{\pi_t} + T^r_t. \tag{3}$$

The household invests in deposits $D_{j,t}$ at the risk-free rate of R^d_t, supplies labour at real wage rate $w_{j,t}$. The government provides a lump-sum transfer to households in the form of T_t, and the central bank provides seignorage revenue, T^r_t[18]. At this point it is worth mentioning that several components of the standard DSGE framework are missing. First, it might be useful to introduce a **cash in advance constraint**. Second, one can certainly include other **securities**, such as equity from firms. Third, this model does not have a **preference shock**, which is considered part and parcel of the modern modeling approach in the DSGE literature (Smets and Wouters, 2003, 2007). These additions could potentially be added to the framework, but they are not the focus of the analysis and therefore excluded initially.

[18]The public sector is not consolidated in this model

3.1.1 Consumption and Savings

The objective function (1) is maximised taking into consideration the flow budget constraint (3); which yields the following first order conditions for consumption and deposit holdings.

$$(\partial C_{j,t}) \qquad (C_{j,t} - hC_{j,t-1})^{-\sigma_c} = \lambda_t^h \tag{4}$$

$$(\partial C_{j,t+1}) \qquad \beta^h \mathbb{E}_t (C_{j,t+1} - hC_{j,t})^{-\sigma_c} = \lambda_{t+1}^h \tag{5}$$

$$(\partial D_{j,t}) \qquad \beta^h \mathbb{E}_t \left[\left(\frac{\lambda_{t+1}^h}{\pi_{t+1}} \right) \right] = \frac{\lambda_t^h}{R_t^d} \tag{6}$$

Combining these equations gives us the **Euler equation.**

$$\beta^h \mathbb{E}_t \left[\frac{(C_{j,t+1} - hC_{j,t})^{-\sigma_c}}{\pi_{t+1}} \right] = \frac{(C_{j,t} - hC_{j,t-1})^{-\sigma_c}}{R_t^d} \tag{7}$$

3.1.2 Labour Supply

Households in supply homogenous labour to an intermediate labour union. Each household j has monopoly power over the supply of its labour services (which means it can set it's own price in the labour market). The labour union differentiates these labour services and sets wages according to a Calvo scheme (Smets and Wouters, 2003; Brzoza-Brzezina et al., 2011). Aggregate labour demand N_t is given by the Dixit-Stiglitz aggregator function,

$$N_t = \left(\int_0^1 (N_{j,t})^{\frac{\eta-1}{\eta}} dj \right)^{\frac{\eta-1}{\eta}} \tag{8}$$

Labour packers, who buy the differentiated labour from the unions, package the and resell the services to intermediate goods producers. The maximisation problem for the labour packers, who try to maximise the production function given by (8), is

$$\max_{N_{j,t}} \left(w_t N_t - \int_0^1 w_{j,t} N_{j,t} dj \right) \tag{9}$$

where w_t^h represents the households differentiated labour wages and w_t the aggregate wage. The first order condition for the maximisation problem is:

$$w_t \frac{\eta}{\eta-1} \left(\int_0^1 (N_{j,t})^{\frac{\eta-1}{\eta}} d^j \right)^{\frac{-1}{\eta-1}} \frac{\eta-1}{\eta} (N_{j,t})^{\frac{-1}{\eta}} - w_{j,t} = 0 \tag{10}$$

and the associated labour demand function is,

$$N_{j,t} = \left(\frac{w_{j,t}}{w_t}\right)^{-\eta} N_t \qquad \forall j \tag{11}$$

where the aggregate wage in the economy is represented by:

$$w_t = \left(\int_0^1 (w_{j,t})^{1-\eta} dj\right)^{\frac{1}{1-\eta}} \tag{12}$$

3.1.3 Wage Setting

In this economy the households set their wages according to Calvo's setting. In this scheme households can optimally adjust their wages after receiving a random signal with probability $(1-\theta_w)$. A household j that receives this signal will be able to set a new nominal wage to maximise their utility subject to the demand for labour services. Households that don't receive the signal can only partially index their wages by past values of inflation according to the following rule,

$$w_{j,t+1} = (\pi_t)^{\tau_w} w_{j,t} \tag{13}$$

This implies that if the household cannot change the wage for k periods that the normalised wage after k periods is $\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} w_{j,t}$. The maximisation problem relies not only on the optimisation of (1) with respect to the budget constraint in (3), but also on the labour demand function presented in (11) and wage indexation formula in (13). This relevant part of the maximisation is given by,

$$\max_{w_{j,t}} \mathbb{E}_t \sum_{k=0}^{\infty} \left(\beta^h \theta_w\right)^k \left[-\frac{1}{1+\sigma_n}(N_{j,t})^{1+\sigma_n} + \lambda_{j,t+s}^h \prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} w_{j,t} N_{j,t+k}\right] \tag{14}$$

subject to

$$N_{j,t+k} = \left(\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} \frac{w_{j,t}}{w_{t+k}}\right)^{-\eta} N_{t+k} \tag{15}$$

All households set the same wage because complete markets allow them to hedge the risk of the timing of wage change; this means we drop the j[19]. The first order condition for this

[19] w_t^* is the common reset price

problem is,

$$\frac{\eta-1}{\eta} w_t^* \mathbb{E}_t \sum_{k=0}^{\infty} \left(\beta^h \theta_w\right)^k \left[\lambda_{t+s}^h \left(\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} \right)^{1-\eta} \left(\frac{w_t^*}{w_{t+k}} \right)^{-\eta} N_{t+k} \right]$$
$$= \mathbb{E}_t \sum_{k=0}^{\infty} \left(\beta^h \theta_w\right)^k \left[\left(\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} \frac{w_t^*}{w_{t+k}} \right)^{-\eta(1+\sigma_n)} (N_{t+k})^{1+\sigma_n} \right] \tag{16}$$

From this we can define:

$$f_t^1 = \frac{\eta-1}{\eta} w_t^* \mathbb{E}_t \sum_{k=0}^{\infty} \left(\beta^h \theta_w\right)^k \left[\lambda_{t+s}^h \left(\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} \right)^{1-\eta} \left(\frac{w_t^*}{w_{t+k}} \right)^{-\eta} N_{t+k} \right] \tag{17}$$

$$f_t^2 = \mathbb{E}_t \sum_{k=0}^{\infty} \left(\beta^h \theta_w\right)^k \left[\left(\prod_{s=1}^{k} \frac{(\pi_{t+s-1})^{\tau_w}}{\pi_{t+s}} \frac{w_t^*}{w_{t+k}} \right)^{-\eta(1+\sigma_n)} (N_{t+k})^{1+\sigma_n} \right] \tag{18}$$

The equality $f_t^1 = f_t^2$ returns the first order condition. It is possible to express f_t^1 and f_t^2 recursively as:

$$f_t^1 = \frac{\eta-1}{\eta} (w_t^*)^{1-\eta} \lambda_t^h (w_t)^{\eta} N_t + \beta^h \theta_w \mathbb{E}_t \left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}} \right)^{1-\eta} \left(\frac{w_{t+1}^*}{w_t^*} \right)^{\eta-1} f_{t+1}^1 \tag{19}$$

$$f_t^2 = \left(\frac{w_t}{w_t^*} \right)^{\eta(1+\sigma_n)} (N_t)^{(1+\sigma_n)} + \beta^h \theta_w \mathbb{E}_t \left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}} \right)^{-\eta(1+\sigma_n)} \left(\frac{w_{t+1}^*}{w_t^*} \right)^{\eta(1+\sigma_n)} f_{t+1}^2 \tag{20}$$

Since $f_t^1 = f_t^2$, we can set $f^t = f_t^1 = f_t^2$, which gives us,

$$f_t = \frac{\eta-1}{\eta} (w_t^*)^{1-\eta} \lambda_t (w_t)^{\eta} N_t + \beta^h \theta_w \mathbb{E}_t \left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}} \right)^{1-\eta} \left(\frac{w_{t+1}^*}{w_t^*} \right)^{\eta-1} f_{t+1} \tag{21}$$

$$f_t = \left(\frac{w_t}{w_t^*} \right)^{\eta(1+\sigma_n)} (N_t)^{(1+\sigma_n)} + \beta^h \theta_w \mathbb{E}_t \left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}} \right)^{-\eta(1+\sigma_n)} \left(\frac{w_{t+1}^*}{w_t^*} \right)^{\eta(1+\sigma_n)} f_{t+1} \tag{22}$$

Finally, given equation (12), the optimal wage setting problem delivers the following real wage index law of motion,

$$w_t^{1-\eta} = \theta_w \left(\frac{(\pi_{t-1})^{\tau w}}{\pi_t} \right)^{1-\eta} (w_{t-1})^{1-\eta} + (1-\theta_w)(w_t{}^*)^{1-\eta} \tag{23}$$

3.2 Firms (f)

Single final good and continuum of intermediate goods produced. Intermediate goods indexed by i, where i is distributed over the unit interval. Final goods sector is perfectly competitive.

Monopolistic competition in the markets for intermediate goods (each product produced by a single firm); these firms produce differentiated goods and sell them to aggregators – who combine them into the final good. In other words final goods producers package the intermediate goods and sell it to households for consumption.

3.2.1 Final-Good Sector

Final goods producers are the aggregators in this economy. They produce a homogenous good Y_t by combining intermediate goods $y_{i,t}$ through a Dixit-Stiglitz technology. The associated production function is,

$$Y_t = \left(\int_0^1 (y_{i,t})^{\frac{\epsilon-1}{\epsilon}} di \right)^{\frac{\epsilon}{\epsilon-1}} \tag{24}$$

where $y_{i,t}$ is the quantity of the intermediate good used in production, ϵ is the elasticity of substitution (time varying markup in the goods market[20]). Final goods produces maximise their profits subject to the production function in (24), taking as given all intermediate goods prices and the final goods price. The maximisation problem of the final goods producer is then,

$$\max_{y_{i,t}} \left(p_t Y_t - \int_0^1 p_{i,t} y_{i,t} di \right) \tag{25}$$

The associated input demand function (same procedure used when calculating the wages) from this problem are,

$$y_{i,t} = \left(\frac{p_{i,t}}{p_t} \right)^{-\epsilon} Y_t \tag{26}$$

and the final goods price is,

$$p_t = \left(\int_0^1 (p_{i,t})^{1-\epsilon} di \right)^{\frac{1}{1-\epsilon}} \tag{27}$$

3.2.2 Intermediate Goods Producers

Continuum of monopolistically competitive intermediate goods producers of unit mass. Firms set their prices, $p_{i,t}$, according to Rotemberg pricing assumption to maximise profit, π^f [21]. In

[20] Smets and Wouters – Shock to this will be interpreted as cost-push shock to inflation equation

[21] As opposed to Calvo – Predetermined interest rate imply that the marginal cost is firm specific

addition to setting their prices they choose the a level of employment, $N_{i,t}$, and the amount they wish to borrow from merchant banks, $L^b_{i,t}$. These firms also default on their loan repayment with probability $1-\psi_t$. In the case of default, firms experience both disutility and pecuniary costs. Combining these elements one finds that the firm maximises profit in the following manner:

$$\max_{\{p_{i,t},N_{i,t},L^b_{i,t},\psi_t,y_{i,t},K_{i,t},\pi^f_t\}} \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^f)^s \left[(\pi^f_{t+s}) - d_\psi(1-\psi_{t+s}) \right] \tag{28}$$

where B^f is the firm discount factor and d_ψ is the disutility parameter associated with default. Each good is produced (supplied) using the following technology,

$$y_{i,t} = K^\alpha_{i,t} N^{1-\alpha}_{i,t} \tag{29}$$

where $K_{i,t}$ is the capital rented by the firm and $N_{i,t}$ the number of workers employed (i.e. labour input rented). Capital accumulation for this firm is characterised by,

$$K_{i,t} = (1-\varphi)K_{i,t-1} + \frac{L^b_{i,t}}{R^c_t}\left[1-\Gamma\left(\frac{L^b_{i,t}}{L^b_{i,t-1}}\right)\right] \tag{30}$$

where φ is the rate at which capital depreciates, Γ is convex investment adjustment cost[22]. In this equation firms replenish their capital stock by borrowing $L^b_{i,t}$ at a price of $\frac{1}{R^c_t}$. Finally the profit function is given by,

$$\begin{aligned} \pi^f_t = \left(\frac{p_{i,t}}{p_t}\right) y_{i,t} - w_t N_{i,t} - \psi_t \frac{L^b_{i,t-1}}{\pi_t} - \frac{\omega_\psi}{2}\left((1-\psi_{t-1})L^b_{i,t-2}\right)^2 \\ -\frac{\varrho}{2}\left(\frac{p_{i,t}}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p} p_{i,t-1}} - 1\right)^2 Y_t \end{aligned} \tag{31}$$

where ω_ψ is the pecuniary cost of default parameter, ϱ is a quadratic price adjustment cost and $\bar{\pi}$ is the steady state value of inflation. The FOC's with respect to capital and labour for this problem are,

$$(\partial N_{i,t}) \qquad w_t = (1-\alpha)K^\alpha_{i,t} {L_{i,t}}^{-\alpha} \tag{32}$$

$$(\partial K_{i,t}) \qquad \lambda^f_{i,t} - \beta^f \mathbb{E}_t[(1-\varphi)\lambda^f_{i,t+1}] = \alpha K^{\alpha-1}_{i,t} L^{1-\alpha}_{i,t} \tag{33}$$

[22]This convex investment adjustment cost function $\Gamma(\cdot)$ is equal to zero at steady state. In addition, the first derivative $\Gamma'(\cdot)$ also equals zero at steady state. The explicit functional form is $\Gamma\left(\frac{L^b_{i,t}}{L^b_{i,t-1}}\right) = \frac{\theta}{2}\left(\frac{L^b_{i,t}}{L^b_{i,t-1}} - 1\right)^2$

which means that the constant returns to scale Cobb-Douglas production function delivers the following marginal cost function,

$$mc_t = \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{r_t}{\alpha}\right)^{\alpha} \tag{34}$$

$$= \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha}\left(\frac{\lambda_t^f - \beta^f \mathbb{E}_t[(1-\varphi)\lambda_{t+1}^f]}{\alpha}\right)^{\alpha} \tag{35}$$

The investment equation derived from the first order conditions for this maximisation problem is,

$$(\partial L_{i,t}^b) \qquad \frac{\lambda_{i,t}^f}{R_t^c}\left(1 - \Gamma\left(\frac{L_{i,t}^b}{L_{i,t-1}^b}\right) - \Gamma'\left(\frac{L_{i,t}^b}{L_{i,t-1}^b}\right)\frac{L_{i,t}^b}{L_{i,t-1}^b}\right)$$
$$= \beta^f \mathbb{E}_t\left[\frac{\psi_{t+1}}{\pi_{t+1}} - \frac{\lambda_{i,t+1}^f}{R_{t+1}^c}\left(\Gamma'\left[\frac{L_{i,t+1}^b}{L_{i,t}^b}\right]\left(\frac{L_{i,t+1}^b}{L_{i,t}^b}\right)^2\right)\right] + (\beta^f)^2\mathbb{E}_t\left[\omega_\psi(1-\psi_{t+1})^2 L_{i,t}^b\right] \tag{36}$$

The default decision is reflected by,

$$(\partial\psi_t) \qquad \frac{L_{i,t-1}^b}{\pi_t} = d_\psi + \beta^f\omega_\psi\left[(1-\psi_t)(L_{i,t-1}^b)^2\right] \tag{37}$$

3.2.2.1 Price setting Rotemberg pricing assumption, so all intermediate firms set the same prices and produce the same quantities (de Walque et al., 2010). Price is set by taking into account the marginal cost, price adjustment cost and the market demand function. The relevant part of the maximisation problem is as follows,

$$\max_{\{p_{i,t}\}} = \mathbb{E}_t \sum_{s=0}^{\infty}(\beta^f)^s\left[\left(\frac{p_{i,t}}{p_t}\right)y_{i,t} - (mc_t)y_{i,t} - \frac{\varrho}{2}\left(\frac{p_{i,t}}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}p_{i,t-1}} - 1\right)^2 Y_t\right] \tag{38}$$

subject to the demand for intermediate goods,

$$y_{i,t} = \left(\frac{p_{i,t}}{p_t}\right)^{-\epsilon} Y_t$$

plugging in the value for $y_{i,t}$ gives the following problem,

$$\max_{\{p_{i,t}\}} \mathbb{E}_t \sum_{s=0}^{\infty}(\beta^f)^s\left[\left(\frac{p_{i,t}}{p_t}\right)\left(\frac{p_{i,t}}{p_t}\right)^{-\epsilon} Y_t - (mc_t)\left(\frac{p_{i,t}}{p_t}\right)^{-\epsilon} Y_t - \frac{\varrho}{2}\left(\frac{p_{i,t}}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}p_{i,t-1}} - 1\right)^2 Y_t\right]$$

The first order condition with respect to $p_{i,t}$ is,

$$\begin{aligned}(\partial p_{i,t}) \qquad & (1-\epsilon)(p_{i,t})^{-\epsilon}(p_t)^{\epsilon-1}Y_t + (\epsilon)mc_t(p_{i,t})^{-\epsilon-1}(p_t)^{\epsilon}Y_t \\ & -\varrho Y_t\left(\frac{p_{i,t}}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}p_{i,t-1}}-1\right)\left(\frac{1}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}p_{i,t-1}}\right) \\ & +\varrho\beta^f\mathbb{E}_tY_{t+1}\left(\frac{p_{i,t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p}p_{i,t}}-1\right)\left(\frac{p_{i,t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p}(p_{i,t})^2}\right)\end{aligned}$$

Aggregate over all retailer prices, i.e. $p_t = \int_0^1 (p_{i,t})di$, gives us the following price Phillips curve:

$$\begin{aligned}&\left(\frac{\pi_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}}-1\right)\frac{\pi_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}} \\ &= \beta^f\mathbb{E}_t\left[\left(\frac{\pi_{t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p}}-1\right)\frac{\pi_{t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p}}\frac{y_{t+1}}{y_t}\right]+\left[\frac{1-\epsilon(1+mc_t)}{\varrho}\right]\end{aligned} \tag{39}$$

3.3 Banking Sector

The banking sector consists of two specialised banks. Deposit banks receives deposits from households at the deposit rate and lends money to the interbank market at the interbank rate. The merchant bank is the link to the firm, it borrows from the interbank market and supplies loans to the firms. Both these banks may face defaults on their loans.

3.3.1 Deposit Banks (l)

Deposit banks lend L_t^l to the interbank market at the interbank rate R_t^l. It is possible, with probability $(1-\delta_t)$, that the bank is not reimbursed for its loan. These banks also receive deposits $D_t^l = \int D_{j,t}dj$ from households, which they must pay at a deposit rate of R_t^d. There is no possibility for deposit banks to default on the loans of households. The maximisation program for the bank is,

$$\max_{\{D_t^l, L_t^l\}} = \mathbb{E}_t\sum_{s=0}^{\infty}(\beta^l)^s\left[\frac{(\pi_{t+s}^l+1)^{1-\sigma_l}}{1-\sigma_l}\right] \tag{40}$$

subject to the constraint

$$\pi_t^l = \frac{D_t^l}{R_t^d} - \frac{D_{t-1}^l}{\pi_t} + \delta_t\frac{L_{t-1}^l}{\pi_t} - \frac{L_t^l}{R_t^l} \tag{41}$$

The formulation of the bank in this model abstracts from real security holdings[23], a supervisory authority and own funds, when compared to the setup in de Walque et al. (2010). The most important contribution to the paper lies with the merchant banks. The first order conditions for this maximisation problem are,

$$(\partial D_t^l) \qquad \frac{1}{R_t^d}\dot{U}_t^l = \beta^l \mathbb{E}_t\left[\frac{1}{\pi_{t+1}}\dot{U}_{t+1}^l\right] \tag{42}$$

$$(\partial L_t^l) \qquad \frac{1}{R_t^l}\dot{U}_t^l = \beta^l \mathbb{E}_t\left[\frac{\delta_{t+1}}{\pi_{t+1}}\dot{U}_{t+1}^l\right] \tag{43}$$

where, $\dot{U}_t^l = (\pi_t^l + 1)^{-\sigma_l}$. These first order conditions are the Euler equations for deposits from households and loans to the interbank market, respectively (de Walque et al., 2010).

3.3.2 Merchant Banks (b)

Merchant banks complete the financial intermediation narrative for the banking sector. These banks, referred to by Goodhart et al. (2006b) as retail banks, borrow money from the interbank market L_t^l at the interbank rate R_t^l, receive government debt B_t (which is issued at the price $1/R_t^b$ and delivers a payoff of one in $t+1$) and receive reserves from the central bank M_t at the nominal policy rate R_t^m. The reserves received are from outright purchases of securities by the central bank (i.e. open market operations). The monetary authority can perform this operation to change the size of its balance sheet (Akhtar, 1997). It is also possible to include repurchase agreements, as presented in Schabert (2015). Repurchase agreements entail overnight transactions in the reserve market so that the overnight rate is kept in line with the policy rate. This type of fine-tuning is not included in this model[24]. Following Schabert (2015), we introduce a collateralised lending constraint on the merchant bank in the form of,

$$M_t = \kappa \cdot \frac{B_{t-1}}{R_t^m \pi_t} \tag{44}$$

where $M_t = M_t^p - \frac{M_{t-1}^p}{\pi_t}$. Merchant banks may choose not to repay their debt, with a probability of $(1-\delta_t)$. Default takes on a very specific character in this model. Banks that default are not excluded form the interbank market. They experience disutility (d_δ) and non-pecuniary costs as a result of this decision. These banks are also the originators of loans for the firms. They provide loans L_t^b at the credit rate of R_t^c. Firms may also choose not to repay their debt, with probability $(1-\alpha_t)$

The banks aim to maximise the present value of profits subject to (44) and the profit equation

[23]This is one thing that I might want to include
[24]Future iterations of this model will surely include this component

(46). The maximisation is also subject to a disutility cost in d_δ,

$$\max_{\{M_t, M_t^P, B_t, L_t^l, L_t^b, \delta t\}} = \mathbb{E}_t \sum_{s=0}^{\infty} (\beta^b)^s \left[\left(\frac{(\pi_{t+s}^b + 1)^{1-\sigma_b}}{1-\sigma_b} \right) - d_\delta (1 - \delta_{t+s}) \right] \tag{45}$$

The real profits of the merchant bank π_t^b is then given by

$$\begin{aligned} \pi_t^b = & \frac{L_t^l}{R_t^l} - \delta_t \frac{L_{t-1}^l}{\pi_t} + \psi_t \frac{L_{t-1}^b}{\pi_t} - \frac{L_t^b}{R_t^c} + \frac{B_{t-1}}{\pi_t} - \frac{B_t}{R_t^b} \\ & - M_t^P + \frac{M_{t-1}^P}{\pi_t} - \frac{\omega_b}{2} \left[(1 - \delta_{t-1}) L_{t-2}^l \right]^2 - M_t (R_t^m - 1) \end{aligned} \tag{46}$$

where ω_b represents a pecuniary cost from defaulting. The first order conditions for this maximisation problem are,

$$\begin{aligned}
(\partial M_t^P) \qquad & \dot{U}_t^b = \beta^b \mathbb{E}_t \left(\frac{\dot{U}_{t+1}^b}{\pi_{t+1}} \right) \\
(\partial M_t) \qquad & \dot{U}_t^b \left(\frac{1}{R_t^m} - 1 \right) = \eta_t \\
(\partial B_t) \qquad & \dot{U}_t^b \frac{1}{R_t^b} = \beta^b \mathbb{E}_t \left(\frac{\dot{U}_{t+1}^b}{\pi_{t+1}} \right) + \frac{\kappa \cdot \eta_{t+1}}{\pi_{t+1}} \\
(\partial L_t^l) \qquad & \dot{U}_t^b \frac{1}{R_t^l} = \beta^b \mathbb{E}_t \left[\left(\frac{\delta_{t+1}}{\pi_{t+1}} \right) \dot{U}_{t+1}^b \right] + (\beta^b)^2 \mathbb{E}_{t+1} \left[\left(\omega_b (1 - \delta_{t+1})^2 L_t^l \right) \dot{U}_{t+2}^b \right] \\
(\partial L_t^b) \qquad & \dot{U}_t^b \frac{1}{R_t^c} = \beta^b \mathbb{E}_t \left[\frac{\psi_{t+1}}{\pi_{t+1}} \dot{U}_{t+1}^b \right] \\
(\partial \delta_t) \qquad & \dot{U}_t^b \frac{L_{t-1}^l}{\pi_t} = d_\delta + \omega_b \beta^b \mathbb{E}_t \left[\left((1 - \delta_t)(L_{t-1}^l)^2 \right) \dot{U}_{t+1}^b \right]
\end{aligned}$$

where, $\dot{U}_t^b = (\pi_t^b + 1)^{-\sigma_b}$. There are a few things here that I need to figure out. Not all of the equations make sense, especially the money holdings one. Perhaps I can set the discount rate for merchant banks equal to that of households, so that it would be the same as the Bredemeir et al. (2015) paper.

3.4 Public Sector

3.4.1 Government

The government in this economy buys goods, has access to lump-sum transfers T_t and issues debt (in the form of bonds). Bonds are held by either the merchant banks B_t or the central bank B_t^c. The total stock of newly issued bonds by the government is $B_t^g = B_t + B_t^c$. Following

Reynard and Schabert (2009) and Schabert (2015) the growth of the bond supply is constant, equal to Ω and exogenously determined. It is given by,

$$B_t^g = \Omega B_{t-1}^g \tag{47}$$

where $\Omega > \beta$. Only short-term risk-free bonds, similar to treasury bills, are considered in this paper; with bonds of longer maturity introduced in a companion piece. The budget constraint for the treasury is,

$$G_t + \frac{B_{t-1}^g}{\pi_t} = \frac{B_t^g}{R_t} + T_t \tag{48}$$

3.4.2 Central Bank

The monetary authority is able to supply money outright through open market purchases (M_t^p); where newly issued money is reflected by, $M_t = M_t^p - \frac{M_{t-1}^p}{\pi_t}$. The central bank collects government bonds in return for newly issued money. In addition, interest accrues at the main refinancing rate R_t^m; which translates to a return of $M_t \cdot R_t^m$ at period t.

The budget constraint for the central bank, following Schabert (2015) is,

$$T_t^r - M_t R_t^m = \frac{B_{t-1}^c}{\pi_t} - \frac{B_t^c}{R_t^b} \tag{49}$$

Following Reynard and Schabert (2009) and Bredemeir et al. (2015), seignorage revenues are presented as,

$$T_t^r = B_t^c \left(1 - \frac{1}{R_t^b}\right) + (R_t^m - 1)M_t \tag{50}$$

Public sector is not consolidated and the central bank transfers go directly to households. When we substitute out the central bank transfers, as in the central bank budget constraint, bond holdings evolve according to,

$$B_t^c - \frac{B_{t-1}^c}{\pi_t} = M_t^p - \frac{M_{t-1}^p}{\pi_t} \tag{51}$$

Following Schabert (2015), we restrict the initial values, $B_{-1}^c = M_{-1}^p$, which leads to a central bank balance sheet condition, with $B_t^c = M_t^p$. In addition, the central bank sets the policy rate according to a feedback rule, which takes into account how the central bank adjusts the policy rate response to changes in its own lags, in inflation, a measure for real output-gap, and contemporary output growth:

$$R_t^m = (R_{t-1}^m)^{\rho_r}(R^m)^{1-\rho_r}\left(\frac{\pi_t}{\pi}\right)^{\rho_\pi(1-\rho_r)}\left(\frac{y_t}{y}\right)^{\rho_y(1-\rho_r)}\left(\frac{y_t}{y_{t-1}}\right)^{\rho_d y(1-\rho_r)} \tag{52}$$

Two instruments exist for the central bank at this point, as indicated in Hörmann and Schabert (2013).

1. *Conventional instrument*: The policy rate, R_t^m.
2. *Quantitative Easing [Size]*: Increase money supply against eligible assets in open market operations by increasing κ.

This paper will be looking at the second part in the discussion section.

3.5 Market Clearing / Aggregation

Final goods market is in equilibrium. Firms and banks directly consume their profits (not owned by households). Aggregate resource constraint is,

$$\begin{aligned} Y_t = {} & C_t + G_t + \pi_t^f + \pi_t^b + \pi_t^l + K_t - (1-\varphi)K_{t-1} + \frac{L_t^b}{R_t^c}\left[\Gamma\left(\frac{L_t^b}{L_{t-1}^b}\right)\right] \\ & + \frac{\omega_b}{2}\left[(1-\delta_{t-1})L_{t-2}^l\right]^2 + \frac{\omega_\psi}{2}\left((1-\psi_{t-1})L_{t-2}^b\right) \\ & + \frac{\kappa}{2}\left(\frac{p_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}p_{t-1}} - 1\right)^2 Y_t \end{aligned} \tag{53}$$

The aggregate production function is,

$$Y_t = K_t^\alpha N_{i,t}^{1-\alpha} \tag{54}$$

The aggregated law of motion for capital is,

$$K_t = (1-\varphi)K_{t-1} + \frac{L_t^b}{R_t^c}\left[1 - \Gamma\left(\frac{L_t^b}{L_{t-1}^b}\right)\right] \tag{55}$$

3.6 Calibration

Calibration of the household, firm and government largely follows the work of Smets and Wouters (2003, 2007), while monetary policy and the banking sector is calibrated to reflect the values presented in de Walque et al. (2010). Calibrated parameters are summarised in

Table 1, where imposed steady states and steady state ratios are presented in Table 2. Implied steady state parameter values are given in the section on steady states in the appendix.

3.7 Model Dynamics

In this section we are will look at the impact on financial stability originating from contractionary interest rate policy (i.e. an increase in the policy rate). We do this by applying an interest rate policy shock, as found in equation (52). For this analysis different values for the haircut, κ, ranging from $0 < \kappa \leq 1$, will be considered, where lower values of the haircut represent a higher required amount of bonds to acquire reserves. As an example, if the value of the haircut is 0.9, then it represents a 90% haircut. Increases in the haircut represents an increase in the size of the balance sheet.

In the analysis of Goodhart et al. (2011) they employ expansionary monetary policy, pegging the relationship between the interest rate and monetary base. We differ in that varying degrees of interest rate sensitivity will be allowed through selection of the value of the haircut parameter.

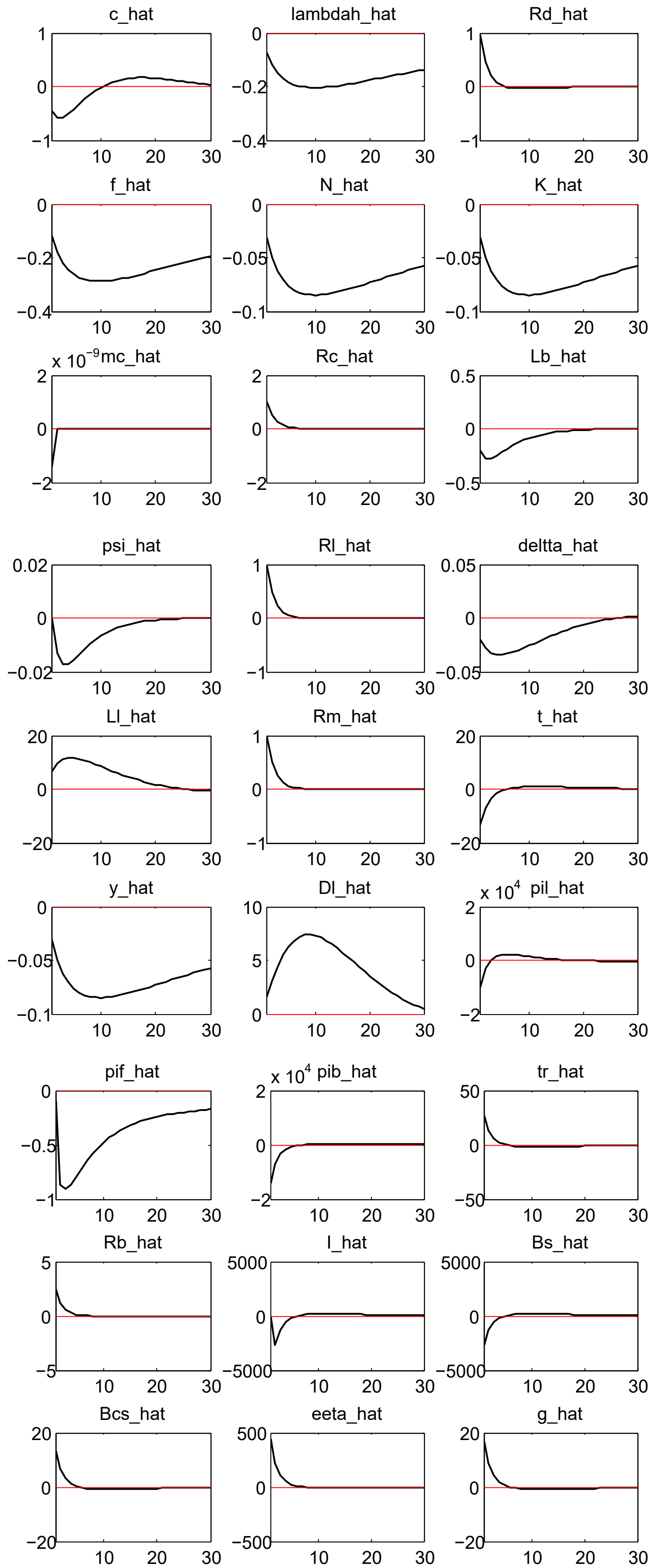
3.7.1 Contractionary Interest Rate Policy

We look at the response of the economy under interest rate policy. Different values for the haircut parameter are chosen, reflecting different scenarios in terms of the size of the balance sheet. Two values at the extremes, 1 and 0.1, are chosen for the analysis. These values represent a 100% and 10% haircut, respectively. There is no theoretical reasoning for these specific values beyond the fact that we are interested in what happens at the extremes. Setting $\kappa = 1$ emulates the case of a one-to-one relationship between interest rates and the quantity of reserves in the economy, as in Goodhart et al. (2011). The impulse response results for $\kappa = 1$ and $\kappa = 0.1$ are given by Figure 1 and Figure 2, respectively[25].

3.7.1.1 Real Sector The first few panels show the traditional hump-shaped responses to a monetary policy tightening, as in Smets and Wouters (2003, 2007). The results are similar for $\kappa = 1$ and $\kappa = 0.1$. In both instances we observe a drop in output, inflation, employment and investment as expected in the case of a policy rate increase. All these variables fall and then gradually converge to the their steady states. Marginal cost experiences a sharp initial

[25] It would be easier to interpret the graphs if they were overlayed. However, due to time constraints the IRFs are presented separately. Future versions of this paper will include all IRFs in one diagram

Figure 1: Contractionary monetary policy, IRF results for $\kappa = 1$



drop, but quickly recovers. Inflation, although not presented here, also drops initially and then returns to steady state[26].

3.7.1.2 Banking Sector The two different types of banks need to be considered individually. First, we consider the case of the deposit bank, which provides liquidity in the interbank market. An increase in the policy rate gets transmitted to the interbank interest rate. In addition, we observe that the repayment rate on interbank loans decreases. Our result confirms the negative relationship between the repayment and interest rate, as shown in de Walque et al. (2010). With increased interest rates the probability of default increases; which translates to a decrease in the repayment rate. Deposit bank profits are negatively affected by the contractionary policy.

Changing the value of κ has a significant effect on the repayment rate in the interbank market. When the value of κ is lowered we observe that the repayment rate decreases; increasing the default rate on interbank loans. Merchant banks in this environment are deprived from access to central bank liquidity due to a harsh haircut requirements. Interestingly, even given the higher interest rate, loans to the interbank market increase[27]. One could justify this increase as a substitution to private bank funds from a decrease in central bank liquidity. In fact, when κ is lowered, decreasing the size of the balance sheet, the demand for interbank loans increases even further.

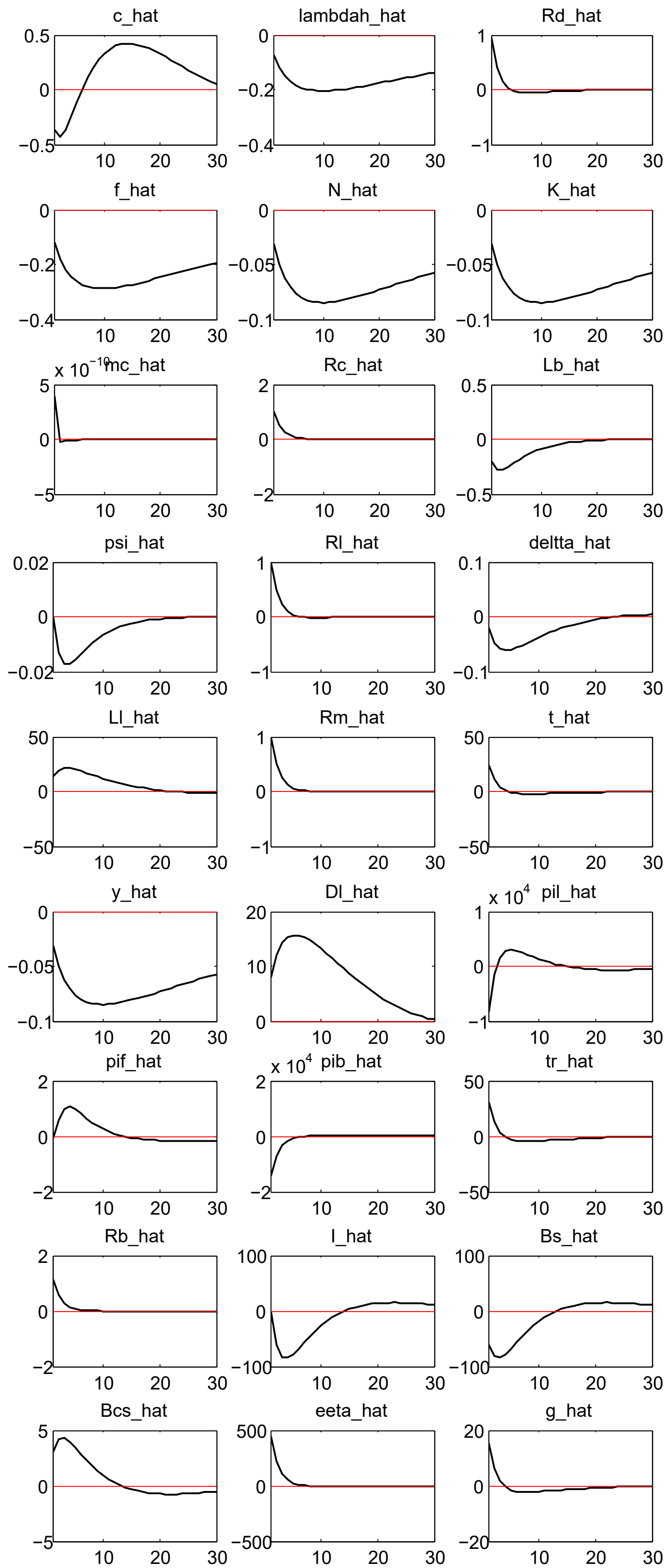
Second, in terms of the merchant bank, we observe a decrease in the repayment rate from loans issued to firms. Monetary policy tightening in this model also results in an increase in the credit rate; which can be seen as the price of loans to firms. Quantity of loans to firms decreases with the increase in price. Both firm and merchant bank profitability decreases as a result of the policy tightening. Changing the value of the haircut does not significantly alter loans to firms, as most of the activity generated takes place in the interbank market.

3.7.1.3 Central Bank The central bank increases the policy rate, which results in a decrease in the quantity of reserves. This negative relationship is indicative of the liquidity effect. Importantly, for lower values of κ we see that the reserve sensitivity to interest rate changes decline; with a subdued effect on the reserves for $\kappa = 0.1$. Selecting a parameter value at the lower end of the spectrum produces an interest rate increase with almost no effect on the quantity of reserves. In this scenario, the effect on bonds matches the change in the size

[26]The reason inflation is not included is because of the threshold imposed by Dynare. If the value of the shock is smaller than a certain threshold, 10^{10} in this case, then the IRF is not shown.

[27]This is in line with the liquidity injection result of de Walque et al. (2010)

Figure 2: Contractionary monetary policy, IRF results for $\kappa = 0.1$



of the balance sheet. This response means that less liquidity is available to merchant banks, which leads to a higher repayment rate than in the case of $\kappa = 1$.

3.8 Conclusion

In conclusion, changes in the size of the balance sheets of central banks to combat financial stability could potentially be as blunt of an instrument as interest rate policy. Central banks in this model have the ability to inject liquidity into the financial system, but without the ability to dictate where the funding ultimately ends up. Liquidity injections will alleviate some of the tension in the interbank markets, but further research is needed to determine whether other policy measures might be more effective. Targeted asset purchases, for example, could perhaps play more of a central role, in a preventive and curative capacity, when it comes to financial instability.

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4 Appendix

4.1 Log-Linearised Model

This section is still a work in progress. Some of the equations need to be changed.

4.1.1 Household

4.1.1.1 Euler Equation The Euler equation is,

$$h\beta^h \mathbb{E}_t \left[\frac{(C_{t+1} - hC_t)^{-\sigma_c}}{\pi_{t+1}} \right] = \frac{(C_t - hC_{t-1})^{-\sigma_c}}{R_t^d}$$

Log-linearisation delivers,

$$\frac{h}{R_{ss}^d (C_{ss} - hC_{ss})^{\sigma_c}} \left[\frac{\sigma_c}{(1-h)} (\hat{C}_t - \hat{C}_{t-1}) + \hat{R}_t^d \right] = \frac{h\beta^h}{\pi_{ss}(C_{ss} - hC_{ss})^{\sigma_c}} \left[\frac{\sigma_c}{(1-h)} (\hat{C}_{t+1} - \hat{C}_t) + \hat{\pi}_{t+1} \right] \quad (56)$$

4.1.1.2 Wage Setting The next equation to consider is the law of motion of f_t. The first part of this equation is given by,

$$f_t = \frac{\eta - 1}{\eta} (w_t^*)^{1-\eta} \lambda_t^h (w_t)^\eta N_t + \beta^h \theta_w \mathbb{E}_t \left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}} \right)^{1-\eta} \left(\frac{w_{t+1}^*}{w_t^*} \right)^{\eta - 1} f_{t+1}$$

Linearising the equation starts as follows,

$$f_{ss}\exp^{\hat{f}_t} = \frac{\eta-1}{\eta}(w^*_{ss})^{1-\eta}\lambda^h_{ss}(w_{ss})^{\eta}N_{ss}\ \exp^{(1-\eta)\hat{w}^*_t+\hat{\lambda}^h_t+\eta\hat{w}_t+\hat{N}_t}$$
$$+\beta\theta_w\pi_{ss}^{(\tau_w-1)(\eta-1)}f_{ss}\mathbb{E}_t\exp^{\hat{f}_{t+1}-(1-\eta)[\hat{\pi}_{t+1}-\tau_w\hat{\pi}_t+\hat{w}^*_{t+1}-\hat{w}^*_t]}$$

With simplification we get,

$$f_{ss}\hat{f}_t = \frac{\eta-1}{\eta}(w^*_{ss})^{1-\eta}\lambda^h_{ss}(w_{ss})^{\eta}N_{ss}\left((1-\eta)\hat{w}^*_t+\hat{\lambda}^h_t+\eta\hat{w}_t+\hat{N}_t\right)$$
$$+\beta\theta_w\pi_{ss}^{(\tau_w-1)(\eta-1)}f_{ss}\mathbb{E}_t\left[\hat{f}_{t+1}-(1-\eta)[\hat{\pi}_{t+1}-\tau_w\hat{\pi}_t+\hat{w}^*_{t+1}-\hat{w}^*_t]\right]$$

In steady state we have that, $f_{ss}-\beta\theta_w f_{ss}\pi_{ss}^{(\tau_w-1)(1-\eta)} = \frac{\eta-1}{\eta}(w_{ss})^{1-\eta}\lambda^h_{ss}w^{\eta}_{ss}N_{ss}$, which we can use to simplify the equation above. The final linearised equation is then,

$$\hat{f}_t = \left(1-\beta\theta_w\pi_{ss}^{(\tau_w-1)(1-\eta)}\right)\left((1-\eta)\hat{w}^*_t+\hat{\lambda}^h_t+\eta\hat{w}_t+\hat{N}_t\right)$$
$$+\beta\theta_w\pi_{ss}^{(\tau_w-1)(\eta-1)}\mathbb{E}_t\left[\hat{f}_{t+1}-(1-\eta)[\hat{\pi}_{t+1}-\tau_w\hat{\pi}_t+\hat{w}^*_{t+1}-\hat{w}^*_t]\right] \tag{57}$$

The second part of the law of motion for f_t is,

$$f_t = \left(\frac{w_t}{w^*_t}\right)^{\eta(1+\sigma_n)}(N_t)^{(1+\sigma_n)}+\beta\theta_w\mathbb{E}_t\left(\frac{(\pi_t)^{\tau_w}}{\pi_{t+1}}\right)^{-\eta(1+\sigma_n)}\left(\frac{w^*_{t+1}}{w^*_t}\right)^{\eta(1+\sigma_n)}f_{t+1}$$

We start by linearising the equation in the following way,

$$f_{ss}\exp^{\hat{f}_t} = \left(\frac{w_{ss}}{w^*_{ss}}\right)^{\eta(1-\sigma_m)}(N_{ss})^{1+\sigma_n}\ \exp^{\eta(1+\sigma_n)[\hat{w}_t-\hat{w}^*_t]+(1+\sigma_n)\hat{N}_t}$$
$$+\beta\theta_w(\pi_{ss})^{\eta(1+\sigma_n)(1-\tau_w)}f_{ss}\mathbb{E}_t\exp^{\hat{f}_{t+1}+\eta(1+\sigma_n)[\hat{\pi}_{t+1}-\tau_w\hat{\pi}_t+\hat{w}^*_{t+1}-\hat{w}^*_t]}$$

From this it can be shown that,

$$f_{ss}\hat{f}_t = \left(\frac{w_{ss}}{w^*_{ss}}\right)^{\eta(1-\sigma_m)}(N_{ss})^{1+\sigma_n}\left(\eta(1+\sigma_n)[\hat{w}_t-\hat{w}^*_t]+(1+\sigma_n)\hat{N}_t\right)$$
$$+\beta\theta_w(\pi_{ss})^{\eta(1+\sigma_n)(1-\tau_w)}f_{ss}\mathbb{E}_t\left(\hat{f}_{t+1}+\eta(1+\sigma_n)[\hat{\pi}_{t+1}-\tau_w\hat{\pi}_t+\hat{w}^*_{t+1}-\hat{w}^*_t]\right)$$

In steady state we have that, $f_{ss}-\beta\theta_w f_{ss}(\pi_{ss})^{\eta(1+\sigma_n)(1-\tau_w)} = \left(\frac{w_{ss}}{w^*_{ss}}\right)^{\eta(1-\sigma_m)}(N_{ss})^{1+\sigma_n}$, which we can use to simplify the equation above. The final linearised equation is then,

$$\hat{f}_t = \left(1-\beta\theta_w(\pi_{ss})^{\eta(1+\sigma_n)(1-\tau_w)}\right)\left(\eta(1+\sigma_n)[\hat{w}_t-\hat{w}^*_t]+(1+\sigma_n)\hat{N}_t\right)$$
$$+\beta\theta_w(\pi_{ss})^{\eta(1+\sigma_n)(1-\tau_w)}\mathbb{E}_t\left(\hat{f}_{t+1}+\eta(1+\sigma_n)[\hat{\pi}_{t+1}-\tau_w\hat{\pi}_t+\hat{w}^*_{t+1}-\hat{w}^*_t]\right) \tag{58}$$

4.1.1.3 Real Wage Index In addition to the law of motion for f_t we have the real wage index, given by,

$$1 = \theta_w \left(\frac{(\pi_{t-1})^{\tau w}}{\pi_t} \right)^{1-\eta} \left(\frac{w_{t-1}}{w_t} \right)^{1-\eta} + (1-\theta_w)(\pi_t^{w^*})^{1-\eta}$$

This equation can be written as,

$$1 = \theta_w \pi_{ss}^{(\tau_w - 1)(1-\eta)} \ \exp^{-(1-\eta)(\hat{\pi}_t - \tau_w \hat{\pi}_{t-1} + \hat{\pi}_t^w)} + (1-\theta_w)(\pi_{ss}^{w^*})^{1-\eta} \ \exp^{(1-\eta)\hat{\pi}_t^{w^*}}$$

Which can then be log-linearised, to give,

$$\theta_w \pi_{ss}^{(\tau_w - 1)(1-\eta)} \left(\hat{\pi}_t - \tau_w \hat{\pi}_{t-1} + \hat{\pi}_t^w \right) = (1-\theta_w)(\pi_{ss}^{w^*})^{1-\eta} \ \hat{\pi}_t^{w^*}$$

This provides us the final linearised equation,

$$\frac{\theta_w \pi_{ss}^{(\tau_w - 1)(1-\eta)}}{(1-\theta_w)(\pi_{ss}^{w^*})^{1-\eta}} \left(\hat{\pi}_t - \tau_w \hat{\pi}_{t-1} + \hat{\pi}_t^w \right) = \hat{w}_t^* - \hat{w}_t \tag{59}$$

4.1.2 Firm

4.1.2.1 Labour The first order condition with respect to labour is,

$$w_t = (1-\alpha) K_t^{\alpha} N_t^{-\alpha}$$

This can be log-linearised to give,

$$\hat{w}_t = \alpha \hat{K}_t - \alpha \hat{N}_t \tag{60}$$

4.1.2.2 Capital The first order condition with respect to capital is,

$$\lambda_t^f - \beta^f \mathbb{E}_t[(1-\varphi)\lambda_{t+1}^f] = \alpha K_t^{\alpha-1} N_t^{1-\alpha}$$

This can be log-linearised to give,

$$\lambda_{ss}^f \hat{\lambda}_t^f - \beta^f \lambda_{ss}^f \mathbb{E}_t[(1-\varphi)\hat{\lambda}_{t+1}^f] = \alpha K_{ss}^{\alpha-1} N_{ss}^{1-\alpha} \left[(\alpha - 1)\hat{K}_t + (1-\alpha)\hat{N}_t \right] \tag{61}$$

4.1.2.3 Marginal Cost The real marginal cost function is,

$$mc_t = \left(\frac{w_t}{1-\alpha} \right)^{1-\alpha} \left(\frac{\lambda_t^f - \beta^f \mathbb{E}_t[(1-\varphi)\lambda_{t+1}^f]}{\alpha} \right)^{\alpha}$$

where we can redefine $r_t = \lambda_t^f - \beta^f \mathbb{E}_t[(1-\varphi)\lambda_{t+1}^f]$, which gives us,

$$mc_t = \left(\frac{w_t}{1-\alpha}\right)^{1-\alpha} \left(\frac{r_t}{\alpha}\right)^{\alpha}$$

Log-linearising this equation gives,

$$\hat{mc}_t = (1-\alpha)\hat{w}_t + \alpha \hat{r}_t$$

The log-linearisation of r_t leaves us with,

$$\hat{r}_t = \frac{\hat{\lambda}_t^f - \beta^f \mathbb{E}_t[(1-\varphi)\hat{\lambda}_{t+1}^f]}{1-\beta^f(1-\varphi)}$$

This gives us the final linearisation of the marginal cost function as,

$$\hat{mc}_t = (1-\alpha)\hat{w}_t + \frac{1}{1-\beta^f(1-\varphi)}\left[\hat{\lambda}_t^f - \beta^f \mathbb{E}_t[(1-\varphi)\hat{\lambda}_{t+1}^f]\right] \tag{62}$$

4.1.2.4 Investment The first order condition with respect to loans from the interbank market is,

$$\begin{aligned}
&\frac{\lambda_t^f}{R_t^c}\left(1 - \Gamma\left(\frac{L_t^b}{L_{t-1}^b}\right) - \Gamma'\left(\frac{L_t^b}{L_{t-1}^b}\right)\frac{L_t^b}{L_{t-1}^b}\right) \\
&= \beta^f \mathbb{E}_t\left[\frac{\psi_{t+1}}{\pi_{t+1}} - \frac{\lambda_{t+1}^f}{R_{t+1}^c}\left(\Gamma'\left[\frac{L_{t+1}^b}{L_t^b}\right]\left(\frac{L_{t+1}^b}{L_t^b}\right)^2\right)\right] + (\beta^f)^2 \mathbb{E}_t\left[\omega_\psi(1-\psi_{t+1})^2 L_t^b\right]
\end{aligned}$$

Log-linearisation leads to the following equation,

$$\begin{aligned}
&\frac{\lambda_{ss}^f}{R_{ss}^c}\left(\hat{\lambda}_t^f - \hat{R}_t^c\right) - \theta\frac{\lambda_{ss}^f}{R_{ss}^c}\left(\hat{L}_t^b - \hat{L}_{t-1}^b\right) + \theta\beta^f\frac{\lambda_{ss}^f}{R_{ss}^c}\mathbb{E}_t\left(\hat{L}_{t+1}^b - \hat{L}_t^b\right) \\
&= \beta^f\frac{\psi_{ss}}{\pi_{ss}}\mathbb{E}_t\left[(\hat{\psi}_{t+1} - \hat{\pi}_{t+1})\right] + (\beta^f)^2\frac{\omega_\psi}{2}(1-\psi_{ss})^2 L_{ss}^b\left[-2\left(\frac{\psi_{ss}}{1-\psi_{ss}}\right)\hat{\psi}_{t+1} + \hat{L}_t^b\right]
\end{aligned} \tag{63}$$

4.1.2.5 Default The first order condition with respect to default is,

$$\frac{L_{t-1}^b}{\pi_t} = d_\psi + \beta^f\omega_\psi\left[(1-\psi_t)(L_{t-1}^b)^2\right]$$

This equation can be written in log-linear form as,

$$\frac{L_{ss}^b}{\pi_{ss}}(1 + \hat{L}_{t-1}^b - \hat{\pi}_t) = d_\psi + \beta^f\frac{\omega_\psi}{2}(1-\psi_{ss})(L_{ss}^b)^2\left[1 - \left(\frac{\psi_{ss}}{1-\psi_{ss}}\right)\hat{\psi}_t + 2\hat{L}_{t-1}^b\right]$$

4.1.2.6 Price Setting Price setting is done in the vein of Rotemberg, given by the following equation,

$$\begin{aligned}&\left(\frac{\pi_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}}-1\right)\frac{\pi_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}}\\&=\beta^f\mathbb{E}_t\left[\left(\frac{\pi_{t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p}}-1\right)\frac{\pi_{t+1}}{(\bar{\pi})^{1-\gamma_p}(\pi_t)^{\gamma_p}}\frac{y_{t+1}}{y_t}\right]+\left[\frac{1-\epsilon(1+mc_t)}{\varrho}\right]\end{aligned}$$

Log-linearisation delivers,

$$\begin{aligned}&\left(\frac{(1+\hat{\pi}_t)}{(1+\gamma_p(\hat{\pi}_{t-1}))}-1\right)\frac{(1+\hat{\pi}_t)}{(1+\gamma_p(\hat{\pi}_{t-1}))}\\&=\beta^f\mathbb{E}_t\left[\left(\frac{(1+\hat{\pi}_{t+1})}{(1+\gamma_p(\hat{\pi}_t))}-1\right)\frac{(1+\hat{\pi}_{t+1})}{(1+\gamma_p(\hat{\pi}_t))}\frac{1+\hat{y}_{t+1}}{1+\hat{y}_t}\right]+\frac{1-\epsilon}{\varrho}-\frac{\epsilon[mc_{ss}(1+\hat{mc}_t)]}{\varrho}\end{aligned}$$

Further simplification yields,

$$[\hat{\pi}_t-\gamma_p(\hat{\pi}_{t-1})]=\beta^f\mathbb{E}_t\left[\hat{\pi}_{t+1}-\gamma_p(\hat{\pi}_t)\right]+\left(\frac{1-\epsilon}{\varrho}\right)\hat{mc}_t \tag{64}$$

4.1.3 Deposit Bank

4.1.3.1 Deposits The first FOC for the deposit bank with respect to deposits is,

$$\left(\frac{1}{R^d_t}-\nu\right)(\pi^l_t+1)^{-\sigma_l}=\beta^l\mathbb{E}_t\left[\left(\frac{1-\nu}{\pi_{t+1}}\right)(\pi^l_{t+1}+1)^{-\sigma_l}\right]$$

Log-linearisation delivers,

$$\begin{aligned}&\frac{1}{R^d_{ss}}\left[\hat{R}^d_t+\left(\frac{\pi^l_{ss}}{1+\pi^l_{ss}}\right)\sigma_l\hat{\pi}^l_t\right]-\nu\left(\frac{\pi^l_{ss}}{1+\pi^l_{ss}}\right)\sigma_l\hat{\pi}^l_t\\&=\beta^l\frac{(1-\nu)}{\pi_{ss}}\left[\left(\frac{\pi^l_{ss}}{1+\pi^l_{ss}}\right)\sigma_l\hat{\pi}^l_{t+1}+\hat{\pi}_{t+1}\right]\end{aligned} \tag{65}$$

4.1.3.2 Interbank Loans The first FOC for the deposit bank with respect to interbank loans is,

$$\frac{1}{R^l_t}(\pi^l_t)^{-\sigma_l}=\beta^l\mathbb{E}_t\left[\frac{\delta_{t+1}}{\pi_{t+1}}(\pi^l_{t+1})^{-\sigma_l}\right]+(\beta^l)^2\tau^l\mathbb{E}_t\left[(1-\delta_{t+1})(\pi^l_{t+2})^{-\sigma_l}\right]$$

Log-linearisation of this equation delivers,

$$\left(\frac{1}{R^l_{ss}(\pi^l_{ss})^{\sigma_l}}\right)(-\hat{R}^l_t - \sigma_l\hat{\pi}^l_t) = \beta^l\left(\frac{\delta_{ss}}{\pi_{ss}(\pi^l_{ss})^{\sigma_l}}\right)(\hat{\delta}_{t+1} - \hat{\pi}_{t+1} - \sigma_l\hat{\pi}^l_{t+1}) + \\ (\beta^l)^2\tau^l\left[-\frac{\delta_{ss}}{(\pi^l_{ss})^{\sigma_l}}\hat{\delta}_{t+1} - \left(\frac{\delta_{ss}-1}{\pi_{ss}(\pi^l_{ss})^{\sigma_l}}\right)\hat{\pi}^l_{t+1}\right] \tag{66}$$

4.1.4 Merchant Bank

4.1.4.1 Interbank Loans The first order condition with respect to interbank loans,

$$\dot{U}^b_t\left(\frac{1}{R^l_t} - \nu)\right) = \beta^b\mathbb{E}_t\left[\left(\frac{\delta_{t+1}-\nu}{\pi_{t+1}}\right)\dot{U}^b_{t+1}\right] + (\beta^b)^2\mathbb{E}_{t+1}\left[\left(\omega_b(1-\delta_{t+1})^2L^l_t\right)\dot{U}^b_{t+2}\right]$$

The final log-linearised equation is,

$$\left[\left(\nu - \frac{1}{R^l_{ss}}\right)\frac{\sigma_b}{(\pi^b_{ss})^{\sigma_b}}\right]\hat{\pi}^b_t - \left(\frac{1}{R^l_{ss}(\pi^b_{ss})^{\sigma_b}}\right)\hat{R}^l_t \\ = \frac{\beta^b}{\pi_{ss}(\pi^b_{ss})^{\sigma_b}}\left[\delta_{ss}\hat{\delta_{t+1}} - \delta_{ss}\hat{\pi}_{t+1} - \delta_{ss}\sigma_b\hat{\pi}^b_{t+1} + \nu\sigma_b\hat{\pi}^b_{t+1}\right] \\ + (\beta^b)^2\omega_b L^l_{ss}(1-\delta_{ss})(\pi^b_{ss})^{-\sigma_b}\left[2\left(\frac{\delta_{ss}}{1-\delta_{ss}}\right)\hat{\delta}_{t+1} + \hat{L}^l_t - \sigma_b\hat{\pi}^b_{t+2}\right] \tag{67}$$

Will have to do this calculation again to check for signs, etc.

4.1.4.2 Loans to Firms The first order condition with respect to loans to firms,

$$\dot{U}^b_t\frac{1}{R^c_t} = \beta^b\mathbb{E}_t\left[\frac{\psi_{t+1}}{\pi_{t+1}}\dot{U}^b_{t+1}\right] + (\beta^b)^2\tau^b\mathbb{E}_t\left[(1-\psi_{t+1})\dot{U}^b_{t+2}\right]$$

The final log-linearised equation is,

$$\left(\frac{1}{R^c_{ss}(\pi^b_{ss})^{\sigma_b}}\right)(-\hat{R}^c_t - \sigma_b\hat{\pi}^b_t) = \beta^b\left(\frac{\psi_{ss}}{\pi_{ss}(\pi^b_{ss})^{\sigma_b}}\right)(\hat{\psi}_{t+1} - \hat{\pi}_{t+1} - \sigma_b\hat{\pi}^b_{t+1}) + \\ (\beta^b)^2\tau^b\left[-\frac{\psi_{ss}}{(\pi^b_{ss})^{\sigma_b}}\hat{\psi}_{t+1} - \left(\frac{\psi_{ss}-1}{\pi_{ss}(\pi^b_{ss})^{\sigma_b}}\right)\hat{\pi}^b_{t+2}\right] \tag{68}$$

4.1.4.3 Newly Issued Reserves The first order condition with respect to newly issued reserves is,

$$\dot{U}^b_t\frac{1}{R^m_t} = \beta^b\mathbb{E}_t\left(\frac{\dot{U}^b_{t+1}}{\pi_{t+1}}\right)$$

This gives the following log-linearised equation,

$$\sigma_b \hat{\pi}_t^b + \hat{R}_t^m = \mathbb{E}_t\left(\hat{\pi}_{t+1} + \sigma_b \hat{\pi}_{t+1}^b\right) \tag{69}$$

4.1.4.4 Default The first order condition with respect to default is

$$\dot{U}_t^b \frac{L_{t-1}^l}{\pi_t} = d_\delta + \omega_b \beta^b \mathbb{E}_t\left[\left((1-\delta_t)(L_{t-1}^l)^2\right)\dot{U}_{t+1}^b\right]$$

The final log-linearisation is,

$$\begin{aligned}&\frac{L_{ss}^l}{\pi_{ss}(\pi_{ss}^b)^{\sigma_b}}\left(\hat{L}_{t-1}^l - \sigma_b\hat{\pi}_t^b - \hat{\pi}_t\right)\\ &= \omega_b\beta^b(1-\delta_{ss})(L_{ss}^l)^2(\pi_{ss}^b)^{\sigma_b}\mathbb{E}_t\left[\left(\frac{\delta_{ss}}{1-\delta_{ss}}\right)\hat{\delta}_t + 2\hat{L}_{t-1}^l - \sigma_b\hat{\pi}_{t+1}^b\right]\end{aligned} \tag{70}$$

4.1.5 Central Bank

4.1.5.1 Budget Constraint The budget constraint of the central bank is,

$$\nu(D_t^l + L_t^l) + T_t = \tau^l(1-\delta_{t-1})L_{t-2}^l + \tau^b(1-\psi_{t-1})L_{t-2}^b - \nu\left(\frac{D_{t-1}^l + L_{t-1}^l}{\pi_t}\right)$$

Log-linearisation gives,

$$\begin{aligned}&\nu(D_{ss}^l\hat{D}_t^l + L_{ss}^l\hat{L}_t^l) + T_{ss}(\hat{T}_t) = \tau^l(1-\delta_{ss})L_{ss}^l\left[\left(\frac{\delta_{ss}}{1-\delta_{ss}}\right)\hat{\delta}_{t-1} + \hat{L}_{t-2}^l\right]\\ &+\tau^b(1-\psi_{ss})L_{ss}^b\left[\left(\frac{\psi_{ss}}{1-\psi_{ss}}\right)\hat{\psi}_{t-1} + \hat{L}_{t-2}^b\right] + \frac{\nu}{\pi_{ss}}\left[D_{ss}^l(\hat{D}_{t-1}^l - \hat{\pi}_t) + L_{ss}^l(\hat{L}_{t-1}^l - \hat{\pi}_t)\right]\end{aligned} \tag{71}$$

4.1.5.2 Feedback Rule Central bank sets the policy rate according to this feedback rule (remember to include the shock to policy $\exp(m_t)$),

$$R_t^m = (R_{t-1}^m)^{\rho_r}(R_{ss}^m)^{1-\rho_r}\left(\frac{\pi_t}{\pi_{ss}}\right)^{\rho_\pi(1-\rho_r)}\left(\frac{Y_t}{Y_{ss}}\right)^{\rho_Y(1-\rho_r)}\left(\frac{Y_t}{Y_{t-1}}\right)^{\rho_d Y(1-\rho_r)}$$

Log-linearisation gives,

$$\hat{R}_t^m = \rho_r(\hat{R}_{t-1}^m) + (1-\rho_r)\left[\rho_\pi\hat{\pi}_t + \rho_Y\hat{Y}_t + \rho_{dY}(\hat{Y}_t - \hat{Y}_{t-1})\right] \tag{72}$$

4.1.6 Market Clearing

4.1.6.1 Market Clearing The market clearing condition is,

$$\begin{aligned}Y_t = C_t + T_t + \pi_t^f + \pi_t^b + \pi_t^l + K_t - (1-\varphi)K_{t-1} + \frac{L_t^b}{R_t^c}\left[\Gamma\left(\frac{L_t^b}{L_{t-1}^b}\right)\right] \\ + \frac{\omega_b}{2}\left[(1-\delta_{t-1})L_{t-2}^l\right]^2 + \frac{\omega_\psi}{2}\left((1-\psi_{t-1})L_{t-2}^b\right) \\ + \frac{\kappa}{2}\left(\frac{p_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}p_{t-1}} - 1\right)^2 Y_t\end{aligned}$$

Log-linearisation gives,

$$\begin{aligned}Y_t = C_t + T_t + \pi_t^f + \pi_t^b + \pi_t^l + K_t - (1-\varphi)K_{t-1} + \frac{L_t^b}{R_t^c}\left[\Gamma\left(\frac{L_t^b}{L_{t-1}^b}\right)\right] \\ + \frac{\omega_b}{2}\left[(1-\delta_{t-1})L_{t-2}^l\right]^2 + \frac{\omega_\psi}{2}\left((1-\psi_{t-1})L_{t-2}^b\right) \\ + \frac{\kappa}{2}\left(\frac{p_t}{(\bar{\pi})^{1-\gamma_p}(\pi_{t-1})^{\gamma_p}p_{t-1}} - 1\right)^2 Y_t\end{aligned} \tag{73}$$

4.1.6.2 Production Function The aggregate production function is,

$$Y_t = K_t^\alpha N_t^{1-\alpha}$$

Log-linearisation gives,

$$\hat{Y}_t = \alpha\hat{K}_t + (1-\alpha)\hat{N}_t \tag{74}$$

4.1.6.3 Capital The aggregated law of motion for capital is,

$$K_t = (1-\varphi)K_{t-1} + \frac{L_t^b}{R_t^c}\left[1 - \Gamma\left(\frac{L_t^b}{L_{t-1}^b}\right)\right]$$

Log-linearisation gives,

$$\hat{K}_t = (1-\varphi)\hat{K}_{t-1} + \frac{L_{ss}^b}{R_{ss}^c K_{ss}}(\hat{L}_t^b - \hat{R}_t^c) \tag{75}$$

4.1.7 Extra Equations

4.1.7.1 Household Budget Constraint Household budget constraint is,

$$T_t + \frac{D^l_t}{R^d_t} + C_t = w_t N_t + \frac{D^l_{t-1}}{\pi_t}$$

Log-linearisation gives us,

$$T_{ss}(\hat{T}_t) + \frac{D^l_{ss}}{R^d_{ss}} \left(\hat{D}^l_t - \hat{R}^d_t\right) + C_{ss}(\hat{C}_t) = w_{ss} N_{ss} \left(\hat{w}_t + \hat{N}_t\right) + \frac{D^l_{ss}}{\pi_{ss}} \left(\hat{D}^l_{t-1} - \hat{\pi}_t\right) \tag{76}$$

4.1.7.2 Indexing Rule The indexing rule is,

$$w_{j,t+1} = (\pi_t)^{\tau_w} w_{j,t}$$

Log-linearisation gives us,

$$\hat{w}_{t+1} - \hat{w}_t = (\pi_{ss})^{\tau_w} (\tau_w \hat{\pi}_t) \tag{77}$$

4.2 Calibration and Steady States

From the Euler equation, given by (7), gives the value for β^h in steady state.

$$\beta = \frac{\pi_{ss}}{R^d_{ss}}$$

To be continued...

Table 1: Calibrated parameters

Parameter	Description	Value
h	Habit formation (consumption)	0.57
β	Discount factor	0.996
σ^c	Coefficient of relative risk aversion	1.35
σ^n	Inverse Frisch elasticity of labour supply	2.4
σ^l	Coefficient for deposit bank (NB)	1.35
σ^b	Coefficient for merchant bank (NB)	1.35
η	Elasticity of substitution between labor varieties	3
ϵ	Elasticity of substitution between goods varieties	3
τ^w	Wage indexation parameter	0.62
θ^w	Calvo parameter (wages)	0.2
α	Capital share of output	0.3
φ	Depreciation rate	0.03
θ	Firms' investment adjustment cost	6.77
ϱ	Price adjustment cost – Calvo parameter (prices)	120
γ_p	Another component of wage adjustment cost	0.47
Γ	Bond supply growth rate	1.0051
ρ_r	Interest rate smoothing coefficient (Taylor Rule)	0.5
ρ_π	Feedback coefficient to inflation in monetary policy rule	1.68
ρ_y	Feedback coefficient to output growth deviation	0.01
ρ_{d^y}	Feedback coefficient to output growth deviation	0.16

Table 2: Imposed Steady States and Ratios

Parameter	Description	Value
π	Inflation	1.0051
R^d	Deposit rate	1.0055
R^c	Credit rate (merchant bank to firms)	1.012
R^l	Interbank borrowing rate	1.0066
R^m	Policy rate (Central Bank)	1.0066
R^b	Treasury bill rate	1.0066
δ	Repayment rate (deposit bank)	0.995
ψ	Repayment rate (merchant bank)	0.975
N	Labour steady state	0.33
C/Y	Consumption spending to output ratio	0.42
π^f/Y	Firm profit to output ratio	0.1
π^l/Y	Deposit bank profit to output ratio	0.0001
π^b/Y	Merchant bank profit to output ratio	0.0001
G/Y	Government spending to output ratio	0.1854
T/Y	Taxation to output ratio	0.187