A monopolistically competitive banking sector

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1 Introduction and related literature

I develop a simple dynamic stochastic general equilibrium (DSGE) model to study how the introduction of a monopolistically competitive banking sector influences the business cycle. The general idea of the model has been inspired by Gerali et al. 2010, whose paper builds a similar, but much detail-richer, model, seeking to investigate not only how banks' market power affects the business cycle but also how macroprudential policies can tame the recurring cycle of booms and busts to ensure moderation. This work is limited to a narrower scope, discussing intuitive ways in which a banking sector can be introduced in an economic model and how this idea affects the standard set of solutions.

The model economy is made up of two sectors and is modelled after the one presented by Ireland 2004: there is a perfectly competitive sector producing the final good and a monopolistically competitive continuum of banks that sells to final sector firms loans to be used as an input in the production process.

Banks sell slightly differentiated loans which are financed by a standing facility at the central bank providing potentially unlimited funds remunerated at the policy rate. In order to maximize model's clarity, there are no other sources of financing, meaning that banks do no hold capital and that their entire flow of profits is entirely distributed to households, owners of the banks.

Firms produce the final good using two inputs: labour, traded in an underlying perfectly competitive market that ensures that the wage is always equal to the marginal productivity of labour, and capital, whose units are exchanged one-for-one with units of loans. This identity allows for a strong simplification, through which loans substitute capital as the second input of production. The profit-maximization behaviour of firms defines the downward-sloping demand for loans faced by banks.

Consumers-households are modelled in the classical RBC way, featuring a double trade-off: a consumption-saving problem and a labour-leisure one, both of which are solved through utility maximizing behaviour.

The goal of the work is two-fold. First, to apply the solution process for DSGE models known as Klein's Method (from Klein 2000) as learned during the Numerical Methods for Economics course to present the dynamic solution of this model economy; this will be done implementing in Python the numerical algorithm described in DeJong and Dave 2011 (Chapter 2). Second, I will study how the model reacts to a set of exogenous disturbances, both to compare the results with classical models lacking a banking sector and to investigate how the banking sector itself impacts the business cycles phases of the economy.

The rest of the paper is organized as follows. Section 2 presents the model in details. Section 3 discusses how the model is reduced and which strategy is adopted to solve it. Section 4 explains how the model is calibrated. Section 5 studies the impulse response functions deriving from realistic exogenous disturbances. Section 6 concludes.

2 The model economy

The economy is made up of consumers who allocate their period income between the purchase of the unique final good and units of a saving account hold at the central bank who fixes its remuneration by choosing the policy rate. Consumers also decide the labor supply which will be used by firms to produce the final goods in conjunction with loans that are purchased from banks. Banks finance their loans by raising funds from the central bank, who asks for a remuneration equal to the policy rate.

The model does not feature price stickiness. This is particularly relevant in the banking sector, because this simplifying assumption implies that banks face only a static problem of choosing in each period their preferred rate, without the need to pay adjustment costs.

This is the main difference with the monopolistically-competitive intermediate sector presented in Ireland 2004 and from which many features of this model are borrowed. As a consequence, the model presents characteristics traceable both to a standard NKM model (e.g., the presence of monopolistically competitive agents) and a classical RBC one (e.g., perfect price flexibility).

2.1 Consumers

The representative consumer maximizes the expected utility given by:

$$\max_{c_t,n_t,d_t} \mathbb{U} = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t [ln(c_t) - \frac{n_t^{\epsilon}}{\epsilon}]$$

which depends positively and in a concave fashion on consumption (c_t) and is affected negatively by (convex, with curvature ϵ) labour disutility (n_t), subject to a per-period constraint given by:

$$p_t c_t + d_t = (1 + r_{t-1})d_{t-1} + w_t n_t + \pi_t \tag{1}$$

which equates total expenditures, i.e., the sum of the quantity purchased of final good at price p_t and of the saving account (d_t), to the sum of total resources, given by the capitalized value of previous period deposits (d_{t-1}), the wage earned by providing labour to final good producing firms ($w_t n_t$) and the stream of profits earned by banks (π_t), which are entirely owned by households.

The first order conditions of the optimization problem reflect the two trade-offs faced by households: how to allocate time between remunerated labour and utility-enhancing leisure and how to distribute resources between consumption today and consumption tomorrow:

$$n_t^{\epsilon-1} = \frac{w_t}{p_t c_t} \tag{2}$$

$$\frac{1}{p_t c_t} = \beta \mathbb{E}_t [\frac{1 + r_{t+1}}{p_{t+1} c_{t+1}}] \tag{3}$$

The first equation equates the marginal disutility of labour to the marginal benefit provided by the quantity of final good that can be purchased by working one unit of time more. The second condition is the usual Euler equation, describing the intertemporal trade-off between consumption and savings.

2.2 Final good producing firms

Firms produce the final good and sell it in a perfectly competitive market. The production process is carried out using capital and consumer's labor as inputs. For model's tractability concerns, from now on I impose an identity between capital and banking loans[1], which are supplied by a continuum of size 1 of monopolistically competitive banks who sell slightly differentiated products (L_{it}), priced at banking-specific loan rates (R_{it}).

Loans' capital and labour are bundled together through a CES aggregator to produce the final good, so that the profits maximization problem faced by the representative firm is:

$$\max_{y_t, L_{it}, n_t} \pi_t = p_t y_t - \int_0^1 R_{it} L_{it}\, di - w_t n_t$$

$$\text{sub. to } \; y_t = [(A_t n_t)^{\frac{\sigma_t - 1}{\sigma_t}} + (\int_0^1 L_{it}\, di)^{\frac{\sigma_t - 1}{\sigma_t}}]^{\frac{\sigma_t}{\sigma_t - 1}} \tag{4}$$

where A_t represents the period t labour-augmenting technology level and σ_t measures the elasticity of substitution between loans and labour in the production process. The CES aggregator is also employed in Gerali et al. 2010, but the authors model loan demand as a separate cost minimization problem for the firm. Here, to simplify the analysis, I borrow from the framework provided by Acemoglu 2002 to directly introduce a continuum of inputs into the representative firm's production function.

It follows that input demands are given by:

$$n_t = (\frac{p_t}{w_t})^{\sigma_t} y_t A_t^{\sigma_t - 1} \tag{5}$$

$$L_{it} = (\frac{p_t}{R_{it}})^{\sigma_t} y_t \tag{6}$$

as shown in appendix A.1.

It follows from (6) that σ_t measures also the elasticity of the demand for loans by firms (see appendix A.2).

Since the firms operate in a perfectly competitive market, profits are equal to zero; hence, plugging back (5) and (6) into the profit equation and equating everything to zero, I recover the price level of the final good:

$$p_t = (\int_0^1 R_{it}^{1-\sigma_t}\, di + (\frac{w_t}{A_t})^{1-\sigma_t})^{\frac{1}{1-\sigma_t}} \tag{7}$$

2.3 Banking sector

The banking sector is populated by a continuum of size 1 of banks that offer slightly differentiated products in the form of loans and, as such, face a downward-sloping demand function from firms given by (6). Banks finance the loans they provide by borrowing entirely from the central bank, whose funds are remunerated at the policy rate just as the households' deposit accounts. Banks' profits are then entirely transferred to households.

This set of assumptions greatly simplifies the balance sheet of banks: the assets side is made up only of loans disbursed to firms, with no investments in other financial products like bonds and no reserves holding; the liabilities side is represented by the matching level of funds needed to provide the loans borrowed from the central bank. Hence, bank's capital is constantly set at 0, since in each period profits are entirely distributed to the owners (i.e., households).

Moreover, I assume that banks do not face adjustment costs when setting the period loan rate. This means that the optimization problem they face is not intertemporal and is given by

[1]This can be rationalized assuming that the firm owns a mine from which it can extract resources that will be later used in the production process only if the work is financed externally (through loans).

the maximization in each period of real profits:

$$\max_{R_{it},L_{it}} \frac{\pi_{it}}{p_t} = \frac{1}{p_t}[(R_{it} - r_t)L_{it}]$$
$$\text{sub. to } \; L_{it} = (\frac{p_t}{R_{it}})^{\sigma_t} y_t$$

Optimality implies that in each period banks choose their respective loan rate as a simple mark-up over the policy rate:

$$R_{it} = \frac{\sigma_t}{\sigma_t - 1} r_t \tag{8}$$

Despite the numerous features introduced to simplify the framework, this result is coherent with the static banking model proposed by Ulate 2019.

Plugging (8) back into the objective function, I get the level of profits for each period:

$$\pi_{it} = \frac{r_t}{\sigma_t - 1} L_{it} \tag{9}$$

2.4 Monetary authority

The central bank set in each period the policy rate according to the following Taylor-like rule (borrowed from Gerali et al. 2010):

$$r_t = \bar{r}^{1-\psi} r_{t-1}^{\psi} (\frac{p_t}{p_{t-1}})^{\vartheta(1-\psi)} (\frac{y_t}{y_{t-1}})^{\gamma(1-\psi)} \eta_t \tag{10}$$

where $\bar{r}$ is the steady state policy rate (implied by households' discount factor), ψ, ϑ, γ are parameters weighing the various components of the rule and η_t is an i.i.d. shock with unitary mean.

The model is closed by assuming that the central bank can provide an unlimited amount of funding to the banking sector at the policy rate, creating money "out of thin air"[2].

2.5 Stochastic components

Finally, I assume that both the technological level prevailing in the economy and the elasticity of substitution that impacts the mark-up charged by banks, follow an AR(1) process in logarithms of the following form:

$$ln(A_t) = (1 - \rho_A) ln(A_0) + \rho_A ln(A_{t-1}) + u_t \tag{11}$$

$$ln(\sigma_t) = (1 - \rho_\sigma) ln(\bar{\sigma}) + \rho_\sigma ln(\sigma_{t-1}) + v_t \tag{12}$$

where A_0 and $\bar{\sigma}$ are the respective steady state level (with $ln(A_0)$ fixed at 1).

3 Analysis of the model and solution

The model, as presented above, is made up of 12 equations featuring 12 unknowns: $\{c_t, n_t, p_t, d_t, r_t, w_t, \pi_t, y_t, R_t, L_t, A_t, \sigma_t\}$. Notice that I dropped the i subscript (indicating the *i-th* bank) from R_t, π_t and L_t. Indeed, as it can be observed from equations (6), (8) and (9), all the banks are symmetric and thus, in equilibrium, will charge the same interest rate, selling the same amount of loans and raising the same profits.

The model is thus described in its entirety by the system of non-linear equations (1)-(12). Before proceeding further, though, I reduce the model to 8 equations into 8 unknowns, by substituting out $\{w_t, R_t, y_t, \pi_t\}$ using equations (2), (4), (8) and (9).

[2]This implies that the central bank is always able to match its assets (loans to banks) to its liabilities (households' deposits) by expanding or shrinking (even to negative territory) its capital, something economists generally agree to.

3.1 Linearization and state space representation

The model is log-linearized around the steady state, so that deviations from the equilibrium can be interpreted as percentage divergences.

The procedure followed is entirely borrowed from DeJong and Dave 2011 (Chapter 2) and involves five consecutive steps:

1. the logarithms of every equation making up the system with respect to both sides is taken;
2. those variables that were not transformed in logarithms through the previous step are now, by exploiting the identity $x_t = e^{ln(x_t)}$;
3. all terms are collected on the left hand side of each equation;
4. the system is solved for its steady state by fixing $x_{t+1} = x_t = \bar{x}$;
5. through use of gradient procedures, implemented in Python, derivatives around the steady state $\bar{x}$ of the system with respect to x_{t+1} and x_t are numerically computed.

Rather than implementing the algorithm described above myself in Python, I use the package provided by Jenkins 2019, whose work has been modeled on the same literature.

The system is therefore described in the form:

$$A\mathbb{E}[x_{t+1}] = Bx_t$$

which allows me to solve it implementing the Klein's method.

3.2 Implementation of the Klein's method

To implement the solution procedure, the set of variables is partitioned in predetermined or state variables (endogenous and exogenous) and non-predetermined or jumping ones. Jumping variables, by definition, are described as the ones involving (potential) forecast errors. In this sense, the model described above includes three predetermined variables: two exogenously determined, A_t and σ_t, and one endogenously determined, r_t, meaning $s_t = [A_t, \sigma_t, r_t]$; and five jumping variables, i.e., $j_t = [L_t, c_t, n_t, d_t, p_t]$.

The solution is represented by a pair of matrices determining the policy (how state variables determine jumping ones) and transition functions (how state variables today determine state variables tomorrow):

$$\begin{aligned} j_t &= Fs_t \\ s_{t+1} &= Ps_t + \epsilon_{t+1} \end{aligned}$$

where $\epsilon_{t+1} = [u_{t+1}, v_{t+1}, \eta_{t+1}]$ collects the exogenous forcing shocks to the stochastic components of the model and the i.i.d. shock to monetary policy rule.

4 Calibrated parameters

I simulate the model by calibrating all the structural parameters. There are 9 of them and I report the assigned values in the appendix B with their respective source.

The values are calibrated to exactly match those presented in Gerali et al. 2010 for the corresponding variables. However, whereas three of them (β, ϵ and $\bar{\sigma}$) where calibrated already in the original paper, the remaining ones were estimated through the implementation of bayesian techniques; here, I calibrate those parameters too by fixing them at their respective mean as reported in Gerali et al. 2010.

It is worth noting that the consumer discount factor β is calibrated to match the one of patient households in the original paper, since these agents only bought deposits but did not borrow (just as the representative agent here).

Moreover, the equilibrium elasticity of substitution between loans ($\bar{\sigma}$), and its persistence and variance parameters, are calibrated to match the elasticity of substitution between loans featured by entrepreneurs, since here only firms can borrow from banks.

Finally, I set the equilibrium technology level to 1 (or 0 in logarithms), to study the impact of technological innovations.

5 Properties of the model

After having outlined the features of the model, the solution strategy and how the parameters were calibrated, I now move to simulate the economy to study through impulse response functions how the introduction of an explicit banking sector impacts both real and financial variables.

The analysis is divided into three parts, each one linked to the three sources of exogenous shock to which the model economy is subject: monetary policy shock (i.e., unexpected deviations from the central bank Taylor rule), technology shock (i.e., variations in labour productivity) and finally, financial shocks, modelled as exogenous fluctuations in the elasticity of loans demand.

Notice that, while monetary policy shocks are one-off, i.e,. i.i.d. disturbances affecting the Taylor rule showing no persistence from period to period, both technological and financial shocks are described by stationary processes showing a high level of persistence across periods.

5.1 Monetary policy shock

The first impulse response function analyzed is the reaction to a contractionary monetary policy shock, here modelled, coherently with Gerali et al. 2010, as a 50 bp increase in the policy rate. The analysis is based on the charts reported in appendix C.1.

As expected, the loan rate, in absence of a change in the markup rate σ, follows the policy rate in its increase. At the same time, households take advantage of the higher policy rate by reshuffling their consumption-saving decision toward the latter, thus causing a drop in consumption.

Still, with respect to this analysis the model appears as not completely satisfactory, being unable to capture the contractionary shock affecting firms. This means that, with respect to a standard model featuring no banking sector, it seems that the credit channel does have an impact of the transmission of the monetary authority's policy stance but not in the expected direction. This is an area where further work in the building of the model is needed to shed light on such a result.

In particular, future work will need to be focused on how better shape the decision from firms regarding loans, separating the need to buy capital necessary for the production process with the choice of the funding strategy.

5.2 Technology shock

The transmission of a technology shock is studied by looking at the dynamic response of the model economy to a one standard deviation increase of the technological level from its equilibrium value (calibrated as a 0.6% increase from the steady state value).

As it can be seen from the charts in appendix C.2, since technology has been modelled as labour-augmenting, the impulse causes both the quantity of labour employed and the equilibrium wage to increase, reshuffling the balance between labour and loans (capital) towards the former in firms' input choices, with the latters showing a decrease.

The increase in productivity is further reflected in a decrease in the final good price which, consequently, boosts consumption. Moreover, the increase in production and the contemporaneous decrease in the price level, given the respective weights of output and inflation in the monetary policy rule, balance out, implying an almost constant policy rate (notice that the scale of the change in r is around 10^{-3}). This also means that, being both the elasticity of loans demand (exogenously determined) and the policy rate almost unmoved, the loan rate is roughly constant as well.

This is to say that the decrease in the loans used as input of production by firms should be entirely attributed to the rise in productivity of labour and is not explained by a change in inputs' relative prices.

Summing up, a technological shock does not meaningfully impact financial variables, just as in a standard RBC model. The explanation for this result is straightforward: the model explicitly rules out price rigidities both in the final good sect, which is perfectly competitive, and in the banking sector, in which banks do not pay an adjustment cost for charging the optimal loan rate on their products.

5.3 Financial shock

In accordance with the strategy adopted by Gerali et al. 2010, the study of how exogenous shocks impacting the banking sector (henceforth simply referenced as financial shocks) are transmitted to real variables is conducted by evaluating the impulse response functions of the model to a variation in the elasticity of loan demand displayed by firms, i.e., σ, whose charts are reported in appendix C.3.

In particular, the deviation from the steady state is again calibrated as an increase of one standard deviation, or 1,97%, from its steady state value. While the model rules out loan rate rigidities, the shock is persistent and its impact will still be felt over time.

From (8), it is immediate to see that the loan rate is negatively dependent on σ, implying a decrease in R.

Moreover, such a decrease drags down prices, thus boosting consumption, with consumers shifting away from deposits (i.e., savings) to take advantage of the transitory low prices.

Above all, the main result of the section is discernible in the way in which the introduction of an explicit (even if limited in details and scope) banking sector, with its self-generated shocks, is capable of producing fluctuations both in financial and real variables, thus confirming the initial intuition that such intermediation effects should be taken into account by policymakers when formulating policy prescriptions.

6 Conclusions

This work has focused on proposing an intuitive model that accounts for the role of banks in shaping the business cycle. While it has been inspired by the paper from Gerali et al. 2010, it has been by no means a simple replication exercise. In particular, I deemed the original model too complicated and full of details to be reproposed here. On the contrary, I decided to rely on the backbone provided by the simple NKM model of Ireland 2004 to implement those features that I found particularly relevant in the original model.

While the result, in my view, presents interesting take-aways, I have no pretense of describing it as complete or exhaustive. Yet, I am confident of having shown how the theory proposed during the Numerical Methods course can be implemented to solve detail-rich models.

Moreover, this analysis opens up a number of relevant questions that lay the groundwork for future research. Among them I list the need to further specify the problem of the firm, dividing the financing problem from the choice of the inputs. Moreover, the banking sector needs to be enriched, widening the balance sheet of financial institutions to take into accounts investments in bonds and other financial instruments as well as the possibility of taking up capital and households' deposits. Finally, it would be interesting to study how banks' activity may cause the arising of financial crisis and how monetary policy authorities can tame those risks through macroprudential policies like requiring banks to hold a minimum amount of capital.

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A Derivation of relevant model features

A.1 Final good producing firms

Henceforth I proceed imposing simmetricity between banks, so that $R_{it} = R_t$ and $L_{it} = L_t \; \forall \; i$.

Given the problem of the firm described in section 2.2, the first order conditions (FOCs) are given by:

$$\frac{\partial L}{\partial y_t} = 0 \rightarrow p_t = \lambda_t$$
$$\frac{\partial L}{\partial n_t} = 0 \rightarrow w_t = \lambda_t(\frac{\sigma_t}{\sigma_t - 1})[(A_t n_t)^{\frac{\sigma_t - 1}{\sigma}} + L^{\frac{\sigma_t - 1}{\sigma_t}}]^{\frac{\sigma_t}{\sigma_t - 1} - 1}(\frac{\sigma_t - 1}{\sigma_t})(A_t n_t)^{\frac{\sigma_t - 1}{\sigma_t} - 1} A_t$$
$$\frac{\partial L}{\partial L_t} = 0 \rightarrow R_t = \lambda_t(\frac{\sigma_t}{\sigma_t - 1})[(A_t n_t)^{\frac{\sigma_t - 1}{\sigma}} + L^{\frac{\sigma_t - 1}{\sigma_t}}]^{\frac{\sigma_t}{\sigma_t - 1} - 1}(\frac{\sigma_t - 1}{\sigma_t}) L_t^{\frac{\sigma_t - 1}{\sigma_t} - 1}$$

Now, using the first FOC in the remaining two, doing simplifications and substituting (4), it is possible to recover both (5) and (6).

To get the price level, as discussed in section 2.2, it is sufficient to impose the zero profit condition, since, by assumption, firms operate in a perfectly competitive market:

$$p_t y_t = R_t(\frac{p_t}{R_t})^{\sigma_t} y_t + w_t(\frac{p_t}{w_t})^{\sigma_t} y_t A_t^{\sigma_t - 1}$$

where both n_t and L_t has been substituted using their respective demand ((5)-(6)). Then it is possible to simplify and rearrange.

A.2 Elasticity of loan demand

The general formula describing an elasticity is:

$$\epsilon_{q,p} = \frac{\partial q}{\partial p} \frac{p}{q}$$

Setting $q = L_{it}$, $p = R_{it}$ and using (6), I have:

$$\epsilon_{L_{it}, R_{it}} = (-\sigma_t) \frac{y_t}{p_t} (\frac{R_{it}}{p_t})^{-\sigma_t - 1} \frac{R_{it}}{(\frac{R_i t}{p_t})^{-\sigma_t} y_t} = -\sigma_t$$

after having simplified all the remaining terms.

B Calibrated parameters

Table 1: Calibrated parameters

Parameter	Description	Source	Value
β	Households discount factor	Gerali et al. 2010, calibrated	0.9943
σ	Steady state elasticity of loan demand	Gerali et al. 2010, calibrated	3.12
α	Inverse of the Frish elasticity[3]	Gerali et al. 2010, calibrated	2.0
A_0	Steady state technological level	Personal calibration	1.0
ρ_A	Technology correlation coefficient	Gerali et al. 2010, estimated	0.936
ρ_σ	Loan demand elasticity correlation coefficient	Gerali et al. 2010, estimated	0.820
ψ	Policy rate persistence	Gerali et al. 2010, estimated	0.77
γ	Output weight in the Taylor rule	Gerali et al. 2010, estimated	0.35
ϑ	Final good price weight in the Taylor rule	Gerali et al. 2010, estimated	2.01
s_A	Technology level standard deviation	Gerali et al. 2010, estimated	0.006
s_σ	Loan demand elasticity standard deviation	Gerali et al. 2010, estimated	0.063

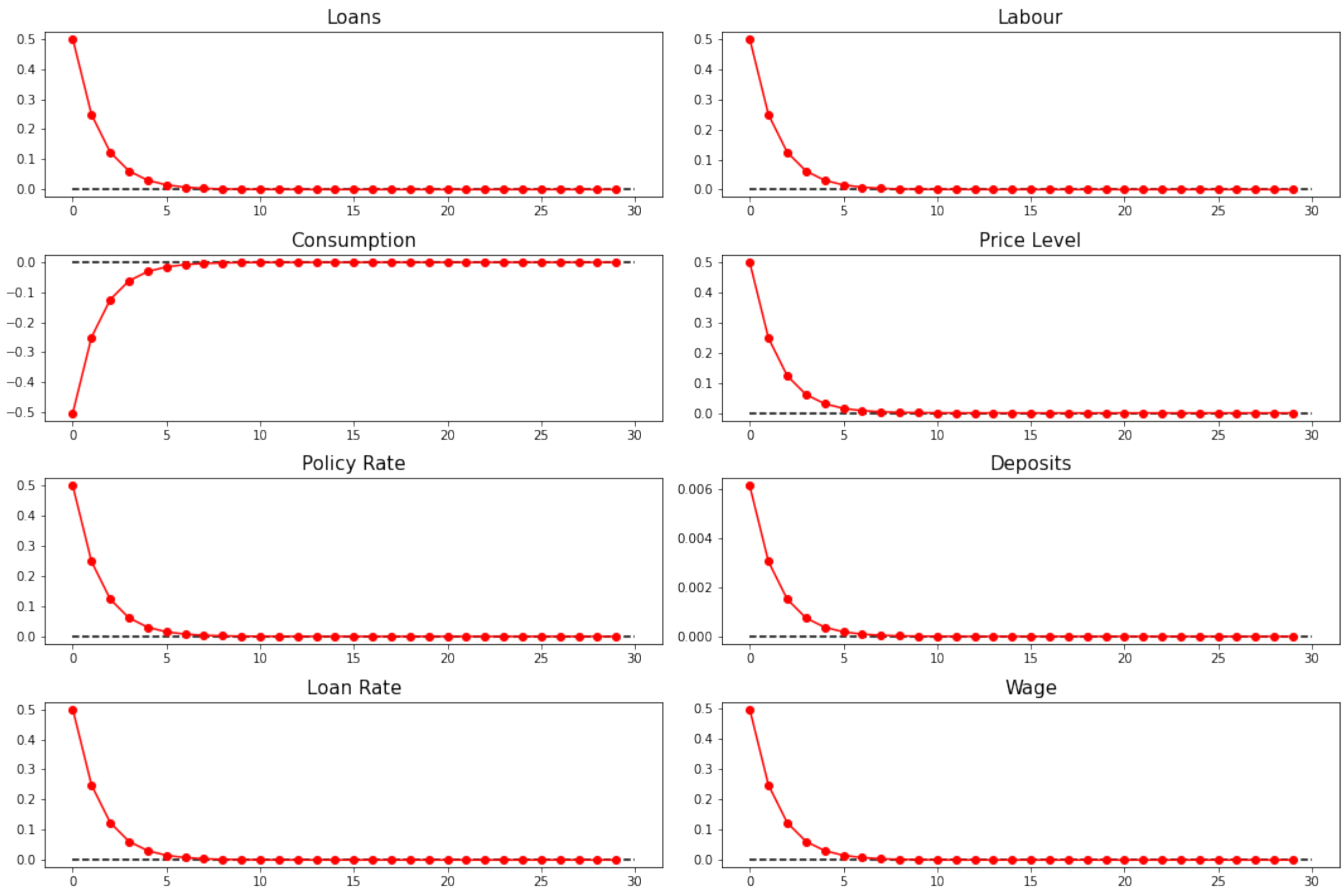
Note: Calibration refers to calibration provided by authors in source. Estimation refers to the use of bayesian techniques by the authors in source; the value reported refers to the mean of such estimates. The steady state technological level is set at 1 so that levels are normalized with respect to the steady state.

[3]Elasticity of labour supply to wage.

C Impulse response functions

C.1 Monetary policy shock

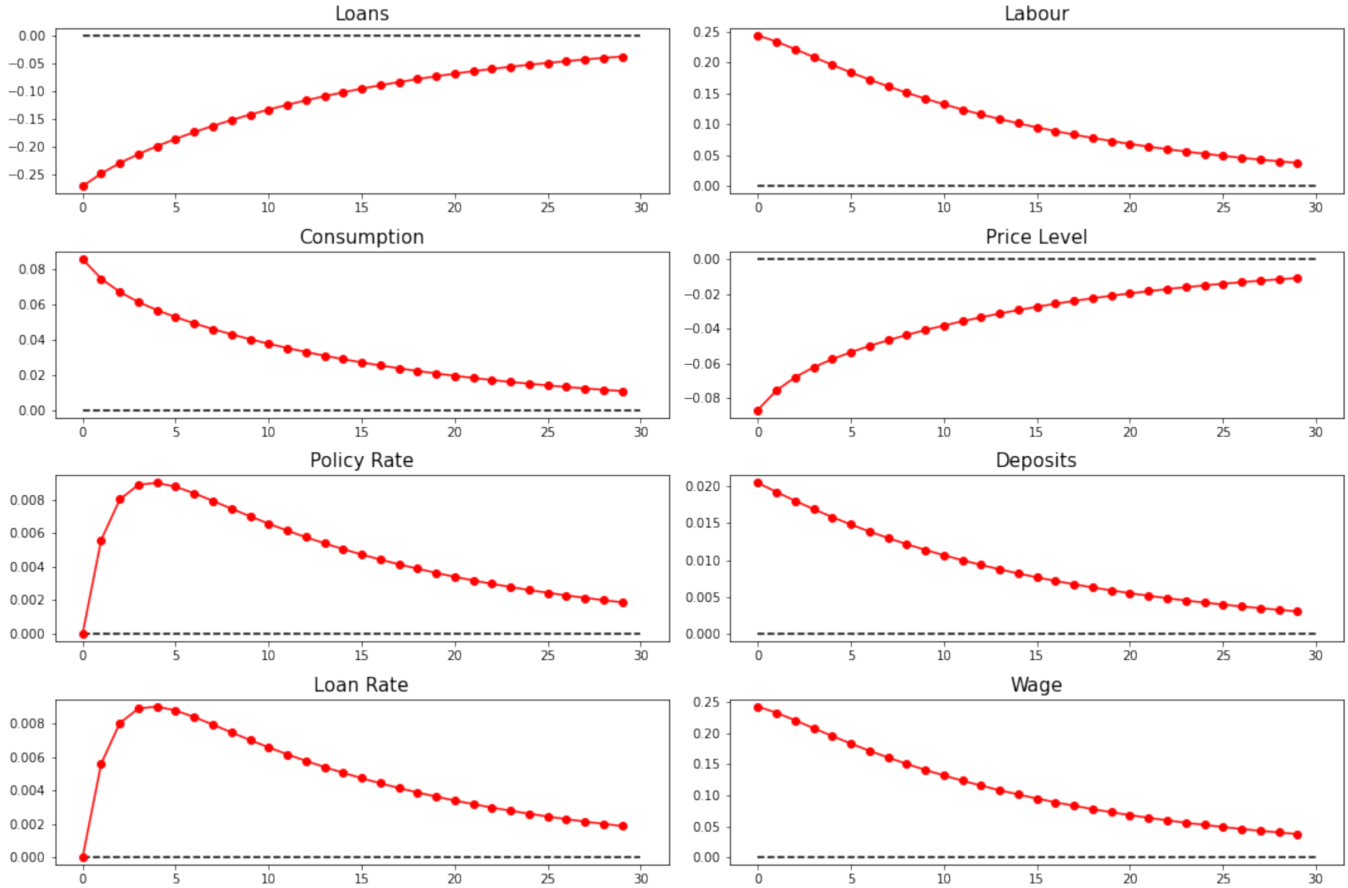
Figure 1: Impulse response function to the transmission of a positive interest rate shock



Note: Deviations (left-hand scale) are shown as percentage deviations from the steady state of the respective variable. The positive interest rate shock (monetary policy tightening) is quantified in an increase of 50 bps of r_t from its steady state.

C.2 Technological shock

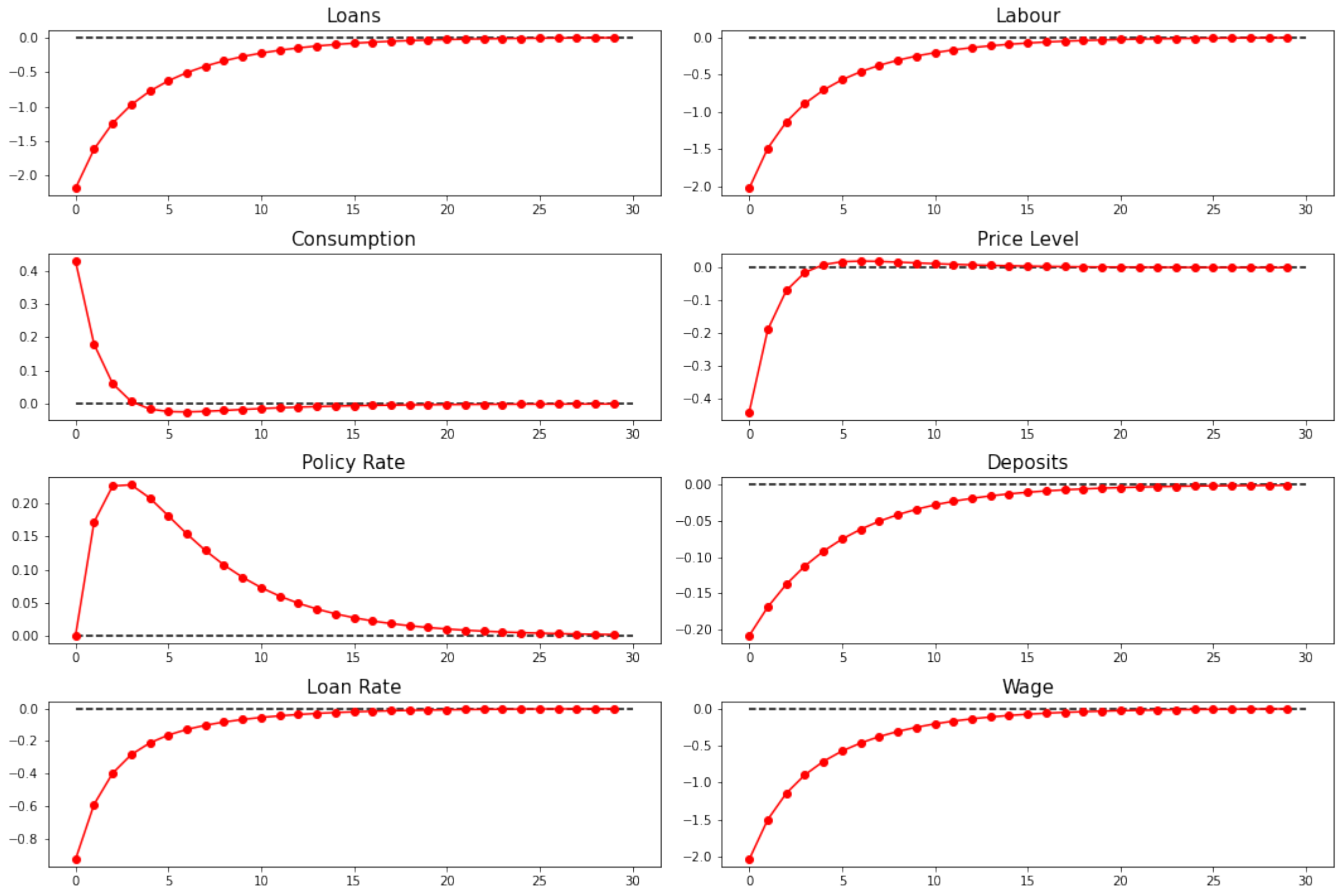
Figure 2: Impulse response function to the transmission of a technological shock



Note: Deviations (left-hand scale) are shown as percentage deviations from the steady state of the respective variable. The positive technological shock is quantified as an increase of A_t of one standard deviation (or 0.6%) from its steady state.

C.3 Financial shock

Figure 3: Impulse response function to the transmission of a positive financial shock



Note: Deviations (left-hand scale) are shown as percentage deviations from the steady state of the respective variable. The positive fianancial shock is quantified as an increase of σ_t of one standard deviation (or 1.97%) from its steady state.