Imperfect Banking Competition and Macroeconomic Volatility: A DSGE Framework

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Abstract

By incorporating a Cournot banking sector into a standard DSGE framework, this paper highlights a new propagation mechanism of imperfect banking competition that operates via the dynamics of the expected marginal product of capital (MPK). A higher expected return on capital implies that firms are more willing to borrow to invest in capital, making their capital and thus loan demand more inelastic. Market power enables banks to take advantage of the lower loan demand elasticity through a higher loan interest margin. Negative shocks that tend to raise the user cost of capital and thus the expected MPK can lead to a higher loan interest margin, which in turn amplifies the output drop.

JEL Classification: E44, E32, G21, L13

Keywords: Imperfect banking competition; Aggregate fluctuations; DSGE

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1 Introduction

The banking sector tends to be dominated by a few large players. In most EU and OECD countries, the largest five banks account for more than 60% of the market.[1] While there has been a growing literature studying the role of financial frictions in amplifying aggregate fluctuations since the global financial crisis, most of the focus is on agency problems between borrowers and lenders. This paper shows that imperfect banking competition, as another important financial friction, can propagate the aggregate fluctuations. Under imperfect banking competition, banks tend to charge a loan rate above the marginal cost. When this loan interest margin endogenously rises during the downturns, it can act as an internal propagation mechanism of macroeconomic shocks.[2]

While there are a few papers studying the time-varying loan interest margin, they often rely on introducing additional frictions or model-specific features on top of the imperfect banking competition. This paper introduces a Cournot banking sector into an otherwise standard dynamic stochastic general equilibrium (DSGE) model. In doing so, the paper reveals a new mechanism behind the time-varying loan interest margin that operates through the general equilibrium dynamics in the expected marginal product of capital (MPK), which is embedded in any DSGE model with physical capital accumulation.

In the model, firms borrow to purchase physical capital one period ahead for production. Each period after production, they sell the undepreciated capital to the capital producers who then invest to produce new capital. Firms borrow up to the point where the expected MPK equals the expected user cost of capital. When the expected marginal product of capital is higher, indicating better investment opportunities, firms are more willing to borrow to finance the purchase of capital. This tends to make their capital and thus loan demand less sensitive to the gross loan rate.[3] Banks with market power respond to a more inelastic loan demand by raising their loan interest margin.

By calibrating the model to match the observed long-run averages of Herfindahl-Hirschman index (HHI) and MPK for each EU country using the data from the European Central Bank

[1] Author's calculation based on ECB and Bankscope data in 2007 and 2014. For empirical evidence on banks' market power using different measures of bank competition, see Corbae and D'Erasmo (2013), Bikker and Haaf (2002), Ehrmann et al. (2001), De Bandt and Davis (2000), Oxenstierna (1999), Berg and Kim (1998), Molyneux, Lloyd-Williams and Thornton (1994), etc.

[2] Olivero (2010) documents that banks' price-cost margin is countercyclical in 58% (using Bankscope data for 1996–2007) to 79% (IMF International Financial Statistics for 1970–2008) of the selected OECD countries. Aliaga-Díaz and Olivero (2010*a*, 2011) provide evidence for the countercyclical loan margin in the US.

[3] If the physical capital fully depreciated every period, the resale value of undepreciated capital would be zero and the user cost of capital would only depend on the loan rate. With a Cobb-Douglas production function and full capital depreciation, the elasticity of capital demand with respect to the loan rate is a constant and does not change over the business cycle.

(ECB) and the Penn World Table during 2008–2017, I find that the model predicted steady state loan interest margins are well aligned with the observed loan interest margins calculated as the difference between the corporate loan interest rates from the ECB and the central bank policy rates from the Bank for International Settlements (BIS). In particular, the steady state loan interest margins in the model can capture the data patterns that the loan interest margins increase in HHI and MPK. I then use the calibrated model to study the dynamics of the loan interest margins and its impact on aggregate fluctuations. There are three main findings.

First, I find that after negative shocks such as a negative capital quality shock and a contractionary monetary policy shock, the expected MPK tends to rise, leading to an increase in the loan interest margin under imperfect banking competition. A higher loan interest margin implies a higher borrowing cost and reduces firms' capital and hence output by more relative to the case of perfect banking competition. A persistently higher loan interest margin due to the dynamics of the expected marginal product of capital can greatly slow down the accumulation of capital and the output recovery.

Second, a negative shock can raise the expected user cost of capital by either raising the real interest rate (e.g. after a contractionary monetary policy shock) or reducing the resale value of the undepreciated capital stock (e.g., after a negative capital quality shock).[4] A higher expected user cost of capital leads to a reduction in the firm's capital below its steady state value and thus raises the expected MPK. Due to the higher expected MPK, the firm would want to purchase more capital over time. This in turn makes their capital and thus loan demand more inelastic. Under imperfect banking competition, banks with market power will take advantage of the more inelastic loan demand by charging a higher loan interest margin.

Third, the magnitude of the amplification effect depends on the extent to which banks with market power internalize the effects of the loan rate on the economy. In the baseline analysis, I assume banks only internalize the direct impact of the loan rate on the firm's capital demand and do not internalize the impacts of the loan rate on the labor market or the aggregate prices. In an extension where banks are assumed to also internalize the indirect impact of the loan rate on the capital demand through the equilibrium labor, I find that the

[4] After a negative productivity shock, there are no exogenous upward forces on the expected user cost of capital. Given the negative productivity shock is a negative supply shock which is inflationary, the real interest rate endogenously rises, which then raises the expected MPK. Meanwhile, the negative productivity shock exerts exogenous downward forces on MPK directly. When the productivity shock is one-time, the expected MPK that depends on future productivity is not affected by this downward force, so the upward force dominates and the loan interest margin rises immediately. If the negative productivity shock is persistent, then the downward force can dominate and the loan interest margin can decrease during the early periods.

steady state loan interest margin and thus the impact of the imperfect banking competition on aggregate fluctuations are smaller. Intuitively, when banks internalize more effects of the loan rate on the economy, a higher loan rate would have a bigger impact on the firm's loan demand, making the loan demand more elastic.

This paper is closely related to the literature on incorporating imperfect banking competition into DSGE models. In the existing literature, imperfect banking competition is often modelled via monopolistic competition within the Dixit and Stiglitz (1977) framework (Airaudo and Olivero, 2019; Hafstead and Smith, 2012; Aliaga-Díaz and Olivero, 2010*b*; Dib, 2010; Gerali et al., 2010; Hülsewig, Mayer and Wollmershäuser, 2009). This monopolistic competition model implies a constant loan rate markup without further assumptions.[5]

There are a few papers that introduce an endogenously changing loan rate markup by using Salop's (1979) model of monopolistic competition (Andrés and Arce, 2012; Olivero, 2010), introducing large banks into the Dixit and Stiglitz (1977) framework (Cuciniello and Signoretti, 2015), or examining limit pricing strategy by banks to deter entry (Mandelman, 2011, 2010). This paper uses a Cournot banking sector to characterize oligopolistic competition among banks. The implication that the loan interest margin decreases in both the number of banks and the loan demand elasticity is similar to the former two approaches. However, what is driving the changes in the loan demand elasticity over the business cycle can be very different depending on the model setup.

The main contribution of this paper is to study the role of imperfect banking competition in a standard DSGE framework that does not require additional model-specific assumptions. While the existing frameworks study the role of imperfect banking competition in specific circumstances, i.e., when firms are financially constrained (Cuciniello and Signoretti, 2015; Andrés and Arce, 2012) or when banks practice limit pricing strategy to deter entry (Mandelman, 2011, 2010), they cannot explain how imperfect banking competition propagates macroeconomic shocks if borrowers are not financially constrained or if the competitive pressure from entry is minimal so that banks do not practice limit pricing to deter entry. By incorporating a Cournot banking sector into an otherwise standard DSGE model, this paper reveals a new propagation mechanism of imperfect banking competition that operates via the dynamics of the expected MPK.

This paper is also related to a large literature that incorporates financial frictions into DSGE models. Most papers incorporate an agency problem between borrowers and lenders,

[5] In all these papers, changes in the loan rate markup over the business cycle are generated by introducing exogenous shocks to the elasticity of substitution between different loan or deposit products (Gerali et al., 2010), bank's marginal cost of producing loans (Hafstead and Smith, 2012), deep habits in banking (Airaudo and Olivero, 2019; Aliaga-Díaz and Olivero, 2010*b*), or interest rate stickiness *à la* Calvo (1983) or Rotemberg (1982) (Dib, 2010; Gerali et al., 2010; Hülsewig, Mayer and Wollmershäuser, 2009).

which is often modeled by costly debt enforcement (e.g., Gertler, Kiyotaki and Queralto, 2012; Gertler and Karadi, 2011; Gertler and Kiyotaki, 2010; Iacoviello, 2005; Kiyotaki and Moore, 1997) or costly state verification (e.g., Christiano, Motto and Rostagno, 2014; Gilchrist, Ortiz and Zakrajsek, 2009; Bernanke, Gertler and Gilchrist, 1999; Carlstrom and Fuerst, 1997; Bernanke and Gertler, 1989).[6] As borrowers' balance sheet conditions worsen during bad times, agency problems become more severe, and the resulting increased difficulty in obtaining external finance tends to amplify any shocks that adversely affect the balance sheet conditions (Bernanke, Gertler and Gilchrist, 1996).

This paper is complementary to this literature by focusing on another important financial friction – imperfect banking competition – that is often overlooked. While the literature often models the credit spread as a function of the borrowers' or financial intermediaries' balance sheet conditions (e.g., Gertler and Karadi, 2011; Bernanke, Gertler and Gilchrist, 1999),[7] this paper models the credit spread as a function of the degree of banking competition and the loan demand elasticity, where the latter depends on the dynamics of the expected MPK embedded in any DSGE model with physical capital accumulation.

The remainder of the paper is structured as follows. Section 2 introduces the DSGE framework with a Cournot banking sector. Section 3 shows the cross-country evidence on the steady state loan interest margins and discusses the model calibration. Section 4 studies the transitory dynamics of aggregate variables after different types of shocks. Section 5 concludes.

2 The Model

There are six types of agents: households, firms, capital producers, retailers, banks, and a central bank. Households consume and supply labor to firms. Firms are perfectly competitive and they buy capital each period from the capital producers and produce wholesale goods using labor and the pre-installed capital. Monopolistically competitive retailers buy wholesale goods from the firms to produce the final consumption good. Perfectly competitive capital producers buy the undepreciated capital from firms and consumption goods from retailers to produce new capital, which is sold back to the firms. Central bank sets the

[6] With a costly debt enforcement problem, borrowers cannot be forced to repay unsecured debt (Beck, Colciago and Pfajfar, 2014), so creditors would not lend an amount that exceeds the value of collateralized assets and borrowers would face a collateral constraint. The costly state verification of Townsend (1979) leads to an endogenous external finance premium, which then raises the cost of borrowing and amplifies business cycle fluctuations.

[7] Recent asset pricing papers also focus on the role of risk premium and relate the financial intermediaries' balance sheet conditions to the credit spread (e.g., Drechsler, Savov and Schnabl, 2018; Muir, 2017; Brunnermeier and Sannikov, 2014; He and Krishnamurthy, 2013).

nominal interest rate following a Taylor rule. Banks provide one-period deposit contracts to the households and loan contracts to the firms that need to borrow to finance the purchase of capital.

This section presents the roles of each agent in turn, which are standard in a DSGE framework except for the banking sector in Section 2.6. Section 2.6.1 shows the problem of a perfectly competitive banking sector, while Section 2.6.2 introduces Cournot banking competition in the loan market and derives the loan interest margin.

2.1 Households

There is a continuum of identical infinitely-lived households of unit mass. The representative household maximizes the following expected utility:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \beta^s [\ln(c_{t+s}) + \phi \ln(1 - l_{t+s})] \tag{1}$$

which depends on consumption c and labor supply l, with $\mathbb{E}_t$ being the expectation operator conditional on information in period t, and $\beta \in (0, 1)$ being the subjective discount factor of the household. The total time endowment is normalized to 1, so $(1 - l_t)$ denotes the amount of period-t leisure time, and $\phi > 0$ is the relative utility weight on leisure.

In each period t, the household consumes c_t, saves d_t in real (final consumption) terms, and supplies labor hours l_t. Assume there is zero net supply of risk-free nominal bonds, so in equilibrium, households hold only nominal bank deposits. The nominal deposits d_{t-1} saved in period $t-1$ earn a gross nominal interest rate R_{t-1} at the beginning of period t. Let p_t denote the unit price of the final consumption good, then the gross inflation rate is $\pi_t \equiv \frac{p_t}{p_{t-1}}$. Given the gross real interest earnings on deposits $\frac{R_{t-1}d_{t-1}}{\pi_t}$ at the beginning of period t, real labor income $w_t l_t$, and real dividends Π_t^F, Π_t^R, Π_t^{CP}, and Π_t^B from firms, retailers, capital producers, and the banking sector, respectively, households decide how much to consume and save in period t. Hence, the representative household faces the following budget constraint:

$$c_t + d_t = \frac{R_{t-1}d_{t-1}}{\pi_t} + w_t l_t + \Pi_t^F + \Pi_t^R + \Pi_t^{CP} + \Pi_t^B \tag{2}$$

Let λ_t denote the Lagrange multiplier associated with the budget constraint or, equivalently, the marginal utility of consumption. The first order conditions with respect to consumption c_t (3), labor supply l_t (4), and bank deposits d_t (5) are as follows:

$$\lambda_t = \frac{1}{c_t} \tag{3}$$

$$\frac{\phi}{1-l_t} = \lambda_t w_t \tag{4}$$

$$1 = \mathbb{E}_t\left[\Lambda_{t,t+1}\frac{R_t}{\pi_{t+1}}\right] \tag{5}$$

where $\Lambda_{t,t+1} \equiv \beta\frac{\lambda_{t+1}}{\lambda_t}$ is the stochastic discount factor in period t for real payoffs in period $t+1$.

2.2 Firms

A continuum of perfectly competitive firms of unit mass purchase new capital k_{t-1} from capital producers at a real price q_{t-1} in period $t-1$ for production in period t. Capital k_{t-1} and labor l_t hired from households are used to produce the wholesale good $y_{w,t}$ via a constant-returns-to-scale Cobb-Douglas production technology:

$$y_{w,t} = z_t(\tau_t k_{t-1})^{\alpha_k} l_t^{\alpha_l} \tag{6}$$

where $\alpha_k \in (0,1)$ and $\alpha_l \in (0,1)$ are the output elasticities of physical capital and labor, respectively. After the capital is installed, there is an exogenous shock that reduces the quality of capital τ_t and thus the effective quantity of capital.[8] The wholesale good produced in period t is sold to retailers at a nominal price $p_{w,t}$, who then produce the final consumption good sold at a nominal price p_t. The productivity z_t and the capital quality τ_t each follows an AR(1) process in logs,

$$\ln z_t = \psi_z \ln z_{t-1} + e_{z,t} \tag{7}$$

$$\ln \tau_t = \psi_\tau \ln \tau_{t-1} + e_{\tau,t} \tag{8}$$

with $\psi_z \in (0,1)$ and $\psi_\tau \in (0,1)$ indicating the persistence of the process, $e_{z,t}$ normally distributed with mean zero and variance σ_z^2, and $e_{\tau,t}$ normally distributed with mean zero and variance σ_τ^2.

Assuming that firms need to take out b_t units of loans in each period t to finance the purchase of new capital at a real capital price q_t from capital producers for production in the following period:

$$b_t = q_t k_t \tag{9}$$

[8] This capital quality shock is often incorporated in DSGE models with financial constraints as an initial disturbance that changes the value of capital (e.g., Gertler and Karadi, 2011), which in turn changes the tightness of the financial constraints. In this paper, the capital quality shock directly reduces the future resale value of undepreciated capital and thus the expected user cost of capital, which in turn raises the expected MPK and the endogenous loan interest margin charged by banks with market power.

Let $R_{b,t-1}$ denote the gross nominal loan rate in period $t-1$, then at the beginning of period t, the gross real loan interest payment is $\frac{R_{b,t-1}b_{t-1}}{\pi_t}$. In each period t, the profit of a firm j equals the sum of the realized output in terms of the final consumption units $\frac{y_{w,t}}{x_t}$ and the revenue from selling the undepreciated capital stock to capital producers $q_t(1-\delta)\tau_t k_{t-1}$, net of the real wage cost $w_t l_t$ and the gross real loan interest payment $\frac{R_{b,t-1}b_{t-1}}{\pi_t}$. The firm chooses the capital k_t and labor l_t to maximize the sum of the expected discounted future profits:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left[\frac{y_{w,t+s}}{x_{t+s}} - w_{t+s}l_{t+s} + q_{t+s}(1-\delta)\tau_{t+s}k_{t+s-1} - \frac{R_{b,t+s-1}b_{t+s-1}}{\pi_{t+s}} \right] \tag{10}$$

where $\Lambda_{t,t+s} \equiv \beta^s \frac{c_t}{c_{t+s}}$ denotes the stochastic discount factor given that households own the firms and $x_t \equiv \frac{p_t}{p_{w,t}}$ denotes the markup of the price of the final consumption good over the price of the wholesale good. Taking the first order conditions with respect to capital (11) and labor (12) gives:

$$\mathbb{E}_t \Lambda_{t,t+1} \left[\frac{z_{t+1}\alpha_k \tau_{t+1}^{\alpha_k} k_t^{\alpha_k - 1} l_{t+1}^{\alpha_l}}{x_{t+1}} + q_{t+1}(1-\delta)\tau_{t+1} - \frac{R_{b,t}q_t}{\pi_{t+1}} \right] = 0 \tag{11}$$

$$\frac{z_t \alpha_l (\tau_t k_{t-1})^{\alpha_k} l_t^{\alpha_l - 1}}{x_t} = w_t \tag{12}$$

As can be seen from (11), firms adjust their demand for physical capital to equate the expected MPK and the expected user cost of capital. The latter consists of the cost of borrowing and the resale value of undepreciated capital. In addition, (11) shows that the firm's capital demand decreases in the gross loan rate $R_{b,t}$ due to the diminishing returns to capital. Section 2.6.2 will show that under imperfect competition in the loan market, banks with market power would take into account the elasticity of the firm's capital demand with respect to the loan rate.

2.3 Capital Producers

Perfectly competitive capital producers purchase undepreciated capital $(1-\delta)\tau_t k_{t-1}$ at the real price q_t from firms and i_t units of final consumption goods from retailers to produce new capital k_t at the end of period t:

$$k_t = i_t + (1-\delta)\tau_t k_{t-1} \tag{13}$$

The new capital produced will be sold back to the entrepreneur at the real price q_t. Assume old capital can be converted one-to-one into new capital, while a quadratic unit investment adjustment cost $f\left(\frac{i_t}{i_{t-1}}\right) = \frac{\chi}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2$ is incurred when using the final consumption good as the input to produce the new capital, where $f(1) = f'(1) = 0$, $f''(1) > 0$ and $\chi > 0$. The representative capital producer chooses the gross investment level i_t to maximize the sum of the expected discounted future profits made from the sales revenue of new capital $q_t k_t$ net of the input cost $[q_t(1-\delta)k_{t-1} + i_t]$ and the investment adjustment cost:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \left[q_{t+s}k_{t+s} - q_{t+s}(1-\delta)\tau_{t+s}k_{t+s-1} - i_{t+s} - \frac{\chi}{2}\left(\frac{i_{t+s}}{i_{t+s-1}} - 1\right)^2 i_{t+s} \right] \tag{14}$$

where $\Lambda_{t,t+s} \equiv \beta^s \frac{c_t}{c_{t+1}}$ is the stochastic discount factor, since households own the capital producers. Taking the first order condition with respect to i_t gives the real price of capital:

$$q_t = 1 + \frac{\chi}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2 + \chi \frac{i_t}{i_{t-1}}\left(\frac{i_t}{i_{t-1}} - 1\right) - \chi \mathbb{E}_t \left[\Lambda_{t,t+1} \left(\frac{i_{t+1}}{i_t}\right)^2 \left(\frac{i_{t+1}}{i_t} - 1\right) \right] \tag{15}$$

In the steady state, the real price of capital q is one, since $i_{t+1} = i_t = i_{t-1}$. Any real profits Π_t^{CP} (which only arise outside the steady state) are rebated to the households, where $\Pi_t^{CP} = (q_t - 1)i_t - \frac{\chi}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2 i_t$. To focus on the main mechanisms, the baseline analysis sets χ to zero, so that the real capital price q_t remains constant at one.

2.4 Retailers

To introduce nominal rigidity, retailers are modeled as monopolistically competitive and thus have the price setting power. Each retailer j uses the wholesale good as the only input to produce a differentiated retail good $y_t(j)$ and charges a nominal price $p_t(j)$. The output of the final consumption good y_t is a constant elasticity of substitution (CES) composite of all the different varieties produced by the retailers:

$$y_t = \left[\int_0^1 y_t(j)^{\frac{\epsilon-1}{\epsilon}} dj \right]^{\frac{\epsilon}{\epsilon-1}} \tag{16}$$

where $\epsilon > 1$ is the elasticity of intratemporal substitution between different varieties. Given the aggregate output index y_t, it can be calculated from the cost minimization problem of the buyers of the final consumption good that each retailer j faces a downward-sloping demand curve:

$$y_t(j) = \left[\frac{p_t(j)}{p_t}\right]^{-\epsilon} y_t \tag{17}$$

where p_t is the aggregate consumption-based price index:

$$p_t = \left[\int_0^1 p_t(j)^{1-\epsilon} dj\right]^{\frac{1}{1-\epsilon}} \tag{18}$$

The price adjustment friction is modeled through Calvo pricing, where a retailer j is only allowed to change its price $p_t(j)$ in period t with a probability $(1-\theta)$ that is independent of the time since the last adjustment. Therefore, in each period, a fraction $(1-\theta)$ of retailers reset their prices whereas a fraction θ of retailers keep their prices fixed. The parameter $\theta \in (0,1)$ reflects the degree of price stickiness.

Let $p_t^*(j)$ denote the optimal reset price in period t; then the corresponding demand facing retailer j who adjusted its price in period t but cannot adjust its price in period $t+s$ is:

$$y_{t+s}^*(j) = \left[\frac{p_t^*(j)}{p_{t+s}}\right]^{-\epsilon} y_{t+s} \tag{19}$$

Retailer j chooses $p_t^*(j)$ to maximize the expected discounted value of real profits while its price is kept fixed at $p_t^*(j)$:

$$\sum_{s=0}^{\infty} \theta^s \mathbb{E}_t \left[\Lambda_{t,t+s} \left\{\frac{p_t^*(j)}{p_{t+s}} y_{t+s}^*(j) - \frac{1}{x_{t+s}} y_{t+s}^*(j)\right\}\right] \tag{20}$$

where $\Lambda_{t,t+s} \equiv \beta^s \frac{c_t}{c_{t+1}}$ is the stochastic discount factor, θ^s is the probability that $p_t^*(j)$ would remain fixed for s periods, and $\frac{1}{x_{t+s}} = \frac{p_{w,t+s}}{p_{t+s}}$ is the real marginal cost of production in period $t+s$, assuming that one unit of the wholesale good can produce one unit of the differentiated product. Taking the first order condition to solve for $p_t^*(j)$ gives the following optimal pricing equation:

$$p_t^*(j) = \frac{\epsilon}{\epsilon - 1} \frac{\sum_{s=0}^{\infty} (\beta\theta)^s \mathbb{E}_t \left[u'(c_{t+s}) x_{t+s}^{-1} p_{t+s}^{\epsilon} y_{t+s}\right]}{\sum_{s=0}^{\infty} (\beta\theta)^s \mathbb{E}_t \left[u'(c_{t+s}) p_{t+s}^{\epsilon-1} y_{t+s}\right]} \tag{21}$$

In a symmetric equilibrium, all the retailers that adjust their prices in period t will set the same optimal price, such that $p_t^*(j) = p_t^*$. With randomly chosen price-adjusting retailers and the large number of retailers, it can be shown that the aggregate price level evolves as follows:

$$p_t^{1-\epsilon} = \theta p_{t-1}^{1-\epsilon} + (1-\theta)(p_t^*)^{1-\epsilon} \tag{22}$$

which is independent of the heterogeneity of the retailers.

2.5 Central Bank

Suppose monetary policy is implemented by a Taylor rule with interest rate smoothing, which responds to both the deviation of the gross inflation rate from the inflation target π and the deviation of output from its steady state y. The central bank controls the gross nominal interest rate R_t on risk-free bonds and bank deposits, following the Taylor rule specification below:

$$R_t = \rho_r R_{t-1} + (1-\rho_r)\left[R + \kappa_\pi(\pi_t - \pi) + \kappa_y\left(y_t - y\right)\right] + e_{r,t} \tag{23}$$

where variables without time subscripts represent steady state values, and $e_{r,t}$ is a monetary policy shock, which is a white noise process with zero mean and variance σ_r^2. The coefficient $\rho_r \in [0,1]$ is the interest rate smoothing parameter, and κ_π and κ_y are non-negative feedback parameters that reflect the sensitivity of the interest rate to output and inflation deviations. With interest rate smoothing, the policy rate R_t is a weighted average of the lagged nominal interest rate R_{t-1} and the current target rate, which depends positively on the deviation of inflation from its target and the deviation of output from its steady state value.

2.6 Banking Sector

Banks offer one-period deposit and loan contracts that are denominated in nominal terms. Therefore, the contracts are not inflation-indexed and the borrowing or saving decisions are made on the basis of a preset contractual nominal loan or deposit rate. Assuming nominal bank deposits and one-period riskless nominal bonds are perfect substitutes to households under full deposit insurance, the nominal deposit rate must equal the nominal interest rate R_t on the riskless nominal bond, which is equivalent to the policy rate set by the central bank in this model.

Section 2.6.1 first shows a perfectly competitive banking sector, where the loan rate equals the deposit rate in equilibrium and thus the loan interest margin is zero, assuming costless financial intermediation. Section 2.6.2 introduces Cournot competition in the loan market, which results in a positive loan interest margin that depends on the degree of banking competition and the loan demand elasticity.

2.6.1 Perfect Banking Competition

Assume there is a continuum of banks of mass one, indexed by j, which are perfectly competitive with no price-setting power. Each bank takes the gross nominal deposit rate R_t and loan rate $R_{b,t}$ as given and chooses the units of loans $b_t(j)$ and deposits $d_t(j)$ to maximize the sum of the expected discounted value of real profits:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \Pi_{t+s}^B(j) \tag{24}$$

subject to the balance sheet identity:

$$b_t(j) = d_t(j) \tag{25}$$

and the budget constraint in real terms:

$$\Pi_t^B(j) + b_t(j) + \frac{R_{t-1} d_{t-1}(j)}{\pi_t} = d_t(j) + \frac{R_{b,t-1} b_{t-1}(j)}{\pi_t} \tag{26}$$

In each period t, the total outflow of funds, consisting of the dividend payment to households $\Pi_t^B(j)$, loans granted to firms $b_t(j)$, and the gross real deposit interest payments to households $\frac{R_{t-1}d_{t-1}(j)}{\pi_t}$, equals the total inflow of funds from the deposits saved by households $d_t(j)$ and the gross real loan interest payments received from firms $\frac{R_{b,t-1}b_{t-1}(j)}{\pi_t}$.

Taking the first order condition with respect to $b_t(j)$ gives:

$$\mathbb{E}_t \left[\Lambda_{t,t+1} \frac{1}{\pi_{t+1}} (R_{b,t} - R_t) \right] = 0 \tag{27}$$

Since $\Lambda_{t,t+1} > 0$ and $\pi_{t+1} \equiv \frac{p_{t+1}}{p_t} > 0$, the nominal loan interest margin $(R_{b,t} - R_t)$ is zero. With perfect banking competition and costless intermediation, the market-determined gross nominal loan rate $R_{b,t}$ equals R_t and therefore, the loan interest margin is zero.

2.6.2 Imperfect Banking Competition

Instead of assuming that the banking sector is perfectly competitive, this section introduces imperfect banking competition into the loan market. I use a Cournot banking sector to characterize oligopolistic competition among banks. The degree of banking competition is captured by the number of banks N. When N approaches infinity, the model nests the perfect banking competition as a special case.

Assume now there are N identical banks in the economy, indexed by j, which operate under Cournot competition in the loan market. Each bank j takes the quantities of loans chosen by the other banks $m \neq j$ as given and chooses its loan quantity $b_t(j)$ to maximize the sum of the present discounted value of future profits:

$$\mathbb{E}_t \sum_{s=0}^{\infty} \Lambda_{t,t+s} \Pi^B_{t+s}(j) \tag{28}$$

where

$$\Pi^B_t(j) = \frac{1}{\pi_t}\left[R_{b,t-1}\left(b_{t-1}(j) + \sum_{m\neq j} b_{t-1}(m)\right) - R_{t-1}\right] b_{t-1}(j) \tag{29}$$

A key difference from Section 2.6.1 is that $R_{b,t}(.)$ now represents the inverse loan demand function, which depends on b_t and thereby $b_t(j)$. As a result, each bank j has some control over the equilibrium gross loan interest rate by choosing its loan quantity $b_t(j)$. Taking the first order condition with respect to $b_t(j)$ and using the equilibrium condition that $b_t(j) = \frac{b_t}{N}$, it is shown in Appendix A.1 that:

$$\mathbb{E}_t\left[\Lambda_{t,t+1}\frac{1}{\pi_{t+1}}\left\{\frac{\partial R_{b,t}}{\partial b_t}\frac{b_t}{N} + R_{b,t} - R_t\right\}\right] = 0 \tag{30}$$

where the market loan demand b_t is given by $b_t = q_t k_t$ (9). Note that $-\frac{\partial b_t}{\partial R_{b,t}}\frac{1}{b_t}$ is the semi-elasticity of the market loan demand. Under Cournot competition, the individual bank's semi-elasticity of loan demand is simply N multiplied by the market loan demand semi-elasticity. Given that $\Lambda_{t,t+1} > 0$ and $\pi_{t+1} \equiv \frac{p_{t+1}}{p_t} > 0$, (30) shows that the loan interest margin, $R_{b,t} - R_t$, or equivalently the difference between the price and the marginal cost, equals the inverse semi-elasticity of the loan demand facing each bank, $-\frac{\partial R_{b,t}}{\partial b_t}\frac{b_t}{N}$.

Loan Interest Margin

Using (30), the equilibrium loan interest margin $(R_{b,t} - R_t)$ can be written as:

$$R_{b,t} - R_t = \frac{1}{N\mathrm{PED}_t - 1} R_t \tag{31}$$

where $\mathrm{PED}_t \equiv -\frac{\partial b_t}{\partial R_{b,t}}\frac{R_{b,t}}{b_t}$ denotes the interest rate elasticity of the market loan demand. Note that under Cournot competition, $N\mathrm{PED}_t$ is each bank's loan demand elasticity. With perfect banking competition (i.e., $N \to \infty$), each bank faces a perfectly elastic loan demand (i.e., $N\mathrm{PED}_t \to \infty$), and therefore $R_{b,t} = R_t$. With Cournot competition, banks with market power can affect the equilibrium loan rate by responding to the endogenously changing loan demand elasticity. From (31), the loan interest margin is higher when N decreases, implying less banking competition, or when PED_t decreases, implying more inelastic market loan demand. Below, I explain how PED_t is endogenously determined in this model.

Loan Demand Elasticity

Since the loan demand is driven by the firm's demand for physical capital, to derive the market loan demand elasticity, we use the firm's first order condition with respect to capital (11) and the labor market equilibrium conditions. Let $\tilde{X}_t = \frac{X_t' - X_t}{X_t}$ denote a small percentage change in X around X_t in period t. It is shown in Appendix A.2 that by log-linearizing (11) around X_t, the percentage change in capital is:

$$\tilde{k}_t = -\frac{1}{1-\alpha_k} \frac{\mathbb{E}_t[\frac{R_{b,t} q_t}{\pi_{t+1}}]}{\mathbb{E}_t \mathrm{MPK}_{t+1}} (\tilde{R}_{b,t} + \tilde{q}_t - \mathbb{E}_t \tilde{\pi}_{t+1}) + \mathbb{E}_t \tilde{l}_{t+1} + \mathbb{E}_t \tilde{\Omega}_{t+1} \tag{32}$$

where $\mathbb{E}_t \mathrm{MPK}_{t+1} \equiv \mathbb{E}_t \left[\frac{z_{t+1} \alpha_k \tau_{t+1}^{\alpha_k} k_t^{\alpha_k - 1} l_{t+1}^{\alpha_l}}{x_{t+1}} \right]$ is the marginal product of capital in real (final consumption) terms and $\mathbb{E}_t \tilde{\Omega}_{t+1} \equiv \frac{1}{1-\alpha_k} \mathbb{E}_t \left[\frac{q_{t+1} \tau_{t+1}(1-\delta)}{\mathrm{MPK}_{t+1}} (\tilde{q}_{t+1} + \tilde{\tau}_{t+1}) + \tilde{z}_{t+1} + \alpha_k \tilde{\tau}_{t+1} - \tilde{x}_{t+1} \right]$ consists of exogenous shocks and changes in aggregate prices.

As can be seen from (32), due to the diminishing returns to capital, when $\tilde{R}_{b,t}$ increases, $\tilde{k}_t$ decreases. Apart from this direct effect of the loan rate on the capital demand, the loan rate can indirectly affect the capital demand through the equilibrium labor and the aggregate prices $(q_t, q_{t+1}, \pi_{t+1}, x_{t+1})$. Here I assume that banks with market power would internalize the direct impact of the loan rate on the firm's capital demand, but do not internalize the impacts of the loan rate on the labor market or the aggregate prices.[9] Given that capital is financed by loans (9), it is shown in Appendix A.2 that the market loan demand elasticity $\mathrm{PED}_t \equiv -\frac{\partial b_t}{\partial R_{b,t}} \frac{R_{b,t}}{b_t}$ is equal to the capital demand elasticity $\mathrm{PEK}_t \equiv -\frac{\partial k_t}{\partial R_{b,t}} \frac{R_{b,t}}{k_t}$.

Therefore, the loan demand elasticity, and equivalently, the capital demand elasticity, is implied by the term in front of $\tilde{R}_{b,t}$ in (32), which can be written as:

$$\mathrm{PED}_t = \frac{1}{1-\alpha_k} \frac{\mathbb{E}_t[\frac{R_{b,t} q_t}{\pi_{t+1}}]}{\mathbb{E}_t \mathrm{MPK}_{t+1}} = \frac{1}{1-\alpha_k} \left(1 + \frac{\mathbb{E}_t[q_{t+1}(1-\delta)\tau_{t+1}]}{\mathbb{E}_t \mathrm{MPK}_{t+1}} \right) \tag{33}$$

where the second equality uses (11).[10] As can be seen, the loan demand is more inelastic if the expected marginal product of capital $\mathbb{E}_t \mathrm{MPK}_{t+1}$ increases or the expected resale value of capital $\mathbb{E}_t[q_{t+1}(1-\delta)\tau_{t+1}]$ decreases. Intuitively, a higher expected MPK implies better investment opportunities for firms. As firms are more willing to borrow to invest in capital, their capital and thus loan demand become more inelastic. A lower expected resale value of capital leads to a greater expected user cost of capital, keeping everything else unchanged.

[9] In Section 4.4, I study the extension where banks also internalize the indirect effect of the loan rate on the equilibrium labor.

[10] Under first-order linear approximation of the model, (11) implies that the expected MPK equals the expected user cost of capital, $\mathbb{E}_t \mathrm{MPK}_{t+1} = \mathbb{E}_t[R_{b,t} q_t / \pi_{t+1} - q_{t+1}(1-\delta)\tau_{t+1}]$.

This in turn raises the expected MPK and makes the loan demand more inelastic.

Note that if the capital fully depreciates every period ($\delta = 1$), then the capital demand elasticity is a constant at $\frac{1}{1-\alpha_k}$. This is because in this case, the user cost of capital no longer depends on the resale value of undepreciated capital and the expected MPK equals the loan rate in equilibrium. With Cobb-Douglas production function, a 1% increase in loan rate leads to a 1% increase in the expected MPK and a $1/(1-\alpha_k)$% drop in the firm's capital. In contrast, when $\delta < 1$, the user cost of capital depends on both the loan rate and the expected resale value of capital. Therefore, when the loan rate increases by 1%, the percentage change in capital demand would also depend on the change in the resale value of capital relative to the user cost of capital.

2.7 Equilibrium Conditions

In equilibrium, the aggregate resource constraint is:

$$c_t + i_t + \frac{\chi}{2}\left(\frac{i_t}{i_{t-1}} - 1\right)^2 i_t = y_t \tag{34}$$

which is also the goods market clearing condition. In equilibrium, households' labor supply equals firms' labor demand and the new capital supplied by capital producers equals firms' capital demand. Let b_t^B and d_t^B denote the total units of loans given out and deposits taken in by the banking sector, respectively. Under perfect banking competition with a continuum of banks of unit mass, $b_t^B = \int_0^1 b_t(j)dj$ and $d_t^B = \int_0^1 d_t(j)dj$, while under Cournot banking competition, $b_t^B = \sum_{j=1}^N b_t(j)$ and $d_t^B = \sum_{j=1}^N d_t(j)$. In equilibrium, the supply of loans from the banking sector b_t^B equals the market loan demand b_t, and the demand for deposits from the banking sector d_t^B equals the supply of deposits from households d_t. Based on banks' balance sheet identity, the total loan supply equals the total deposit holding $b_t^B = d_t^B$.

3 Cross-country Empirical Evidence and Calibration

As shown in Section 2.6.2, a key differentiating feature between perfect and imperfect banking competition is the loan interest margin. Section 3.1 shows the cross-country empirical evidence for the relationship between the steady state loan interest margin and its key determinants, the number of banks and the MPK. In Section 3.2, I discuss the calibration of the model parameters to match the data moments.

3.1 Cross-country Empirical Evidence

With imperfect banking competition, the loan rate no longer equals the policy rate and the loan interest margin $(R_{b,t} - R_t)$ decreases in the number of banks N and increases in the expected MPK, as shown in Section 2.6.2. While it is challenging to measure the expected MPK in the data and study its relationship with the time-varying loan interest margin from the data, it is possible to measure the static MPK and study its relationship with the steady state loan interest margin.

This section provides some supporting empirical evidence for the steady state relationship between the loan interest margin and the number of banks and the MPK using data for the EU countries from 2000–2017. The main reason for using the sample of EU countries is because the ECB provides the corporate loan interest rates data that are comparable across countries. Using (31) and (33), it can be shown that the steady state loan interest margin is:

$$R_b - R = \frac{\frac{1}{\beta}}{\frac{N}{(1-\alpha_k)}\left(1 + \frac{1-\delta}{\text{MPK}}\right) - 1} \tag{35}$$

where R_b is the endogenous steady state gross loan rate and R is the exogenous steady state gross deposit rate or policy rate determined by $1/\beta$. I measure R_b using the corporate loan rates from the ECB Monetary Financial Institutions (MFI) interest rates database. The deposit rate, or equivalently, the policy rate R in the model, is measured using the central bank policy rates from the BIS. The loan interest margin is calculated as the difference between the two.

As can be seen from (35), when N is higher, indicating more bank competition and less bank market power, the steady state loan interest margin is lower. Since banks are identical in the model, N can be measured using the inverse of the HHI in the data.[11] In addition, the steady state loan interest margin increases in $\text{MPK} \equiv \frac{\alpha_k y}{k}$.[12] I measure MPK using the Penn World Table data for the output elasticity of labor α_l, output y, and capital k. Under constant returns to scale, α_k can be found from $(1 - \alpha_l)$.

Table 1 shows the results from regressing the loan interest margins on the HHI and the MPK for 28 EU countries over 2000–2017. As expected, both the HHI (inverse of N) and the MPK have a positive impact on the loan interest margin. There is very little variation in the

[11] With N identical banks in the market, each bank has a market share of $1/N$. Therefore, HHI is the sum of each bank's market share squared, i.e., $\text{HHI} = \sum(\frac{1}{N})^2 = 1/N$.

[12] Note that in Section 2.6.2, $\text{MPK} \equiv \frac{\alpha_k y}{k}\frac{1}{x}$ is defined in terms of the final consumption terms, where x is the markup of the final good price over the wholesale good price. As will be shown in Section 3.2, x equals 1.2 under the standard calibration for the elasticity of substitution among differentiated retail goods $\epsilon = 6$. Assuming x is the same for all countries in the sample, it is just a scaling factor and can be neglected when calculating the MPK.

MPK within a country over time, so the coefficient for the MPK is estimated mostly using the cross-country variation.[13] This explains why the estimate for the MPK is not significant in columns (6) and (9) when the country fixed effects are added on top of the year fixed effects and thus the cross-country variation is reduced.[14]

Table 1: Impact of Bank Concentration and MPK on Loan Interest Margins

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
HHI	5.549***	4.533***	7.508***				6.214***	5.261***	7.826***
	(0.938)	(0.905)	(2.001)				(0.933)	(0.896)	(2.064)
MPK				8.673***	8.167***	6.986	10.052***	9.489***	9.251
				(3.109)	(2.982)	(6.761)	(3.036)	(2.923)	(6.663)
Observations	396	396	396	398	398	398	396	396	396
Adjusted R^2	0.051	0.188	0.773	0.044	0.197	0.762	0.113	0.244	0.775
Year Fixed Effect		Yes	Yes		Yes	Yes		Yes	Yes
Country Fixed Effect			Yes			Yes			Yes

Robust standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Data sources: ECB, BIS central bank policy rates, Bulgarian central bank website, Penn World Table 10.0
Note: The table shows the results from regressing the loan interest margins ($R_b - R$) on the Herfindahl–Hirschman index (HHI), the MPK $\equiv \alpha_k y/k$, and various fixed effects, using the data for EU countries during 2000–2017.

3.2 Targeted Moments and Calibration

This section calibrates the model parameters to match the targeted moments in each EU country. The parameters are calibrated to a quarterly frequency. With the calibrated parameters for each country, I show that the model is able to capture the positive relationship between loan interest margins and HHI across countries observed in the data. I select the country with the highest HHI for the dynamic analysis in Section 4.

Table 2 shows the main targeted moments for each EU country, i.e., the HHI from the ECB Macroprudential database, the central bank policy rate from the BIS, and the output elasticity of labor α_l and the annual labor hours from the Penn World Table. As discussed in Section 3.1, MPK is calculated using the data from the Penn World Table. The numbers in the table are averaged over a 10-year period from 2008–2017 for each country to reflect

[13]Conditional on each country, I calculate the ratio of the standard deviation of the MPK over its mean value over time. On average across these countries, this ratio for MPK is only around 0.08, indicating little variation in the MPK over time within a country. By comparison, the ratio for the HHI is relatively larger at around 0.15.

[14]Despite this, the t-statistic for the MPK in column (9) is around 1.4, which is close to the threshold of 1.67 for significance at a 10% level. In cases where the earlier years (e.g., only 11 countries have data on the loan interest margin in 2000–2002) are removed from the sample, the estimate for the MPK can be significant at a 10% level.

the long-run equilibrium values. These moments are used to calibrate the number of banks N, the depreciation rate δ, the household discount factor β, the output elasticity of capital $\alpha_k = (1 - \alpha_l)$, and the relative utility weight on leisure time ϕ, respectively.

Table 2: Target Data Moments for Each EU Country

Country	HHI	MPK	Policy rate (%)	α_l	Labor Hours
Austria	0.04	0.07	0.90	0.58	1646
Belgium	0.12	0.06	0.90	0.61	1579
Bulgaria	0.08	0.17	0.81	0.50	1649
Croatia	0.14	0.07	0.32	0.59	1857
Cyprus	0.13	0.05	0.90	0.57	1836
Czech Republic	0.10	0.07	0.74	0.52	1781
Denmark	0.12	0.07	0.55	0.63	1419
Estonia	0.26	0.08	0.90	0.58	1877
Finland	0.10	0.08	0.90	0.60	1621
France	0.06	0.06	0.90	0.62	1529
Germany	0.03	0.08	0.90	0.62	1410
Greece	0.18	0.05	0.90	0.53	2049
Hungary	0.09	0.08	3.53	0.57	1749
Ireland	0.07	0.13	0.90	0.43	1766
Italy	0.04	0.06	0.90	0.52	1746
Latvia	0.11	0.05	0.90	0.53	1933
Lithuania	0.18	0.11	0.90	0.50	1894
Luxembourg	0.03	0.09	0.90	0.56	1516
Malta	0.14	0.11	0.90	0.52	2025
Netherlands	0.21	0.08	0.90	0.60	1424
Poland	0.06	0.16	3.16	0.56	2046
Portugal	0.12	0.04	0.90	0.60	1877
Romania	0.09	0.15	5.03	0.46	1813
Slovakia	0.12	0.09	0.90	0.53	1770
Slovenia	0.11	0.04	0.90	0.65	1665
Spain	0.07	0.07	0.90	0.57	1700
Sweden	0.09	0.08	0.85	0.55	1626
United Kingdom	0.05	0.08	0.89	0.59	1658

Data sources: ECB, Bulgarian central bank website, BIS, Penn World Table 10.0
Note: The table shows the Herfindahl–Hirschman index (HHI), the MPK, policy rates, labor share α_l, and annual labor hours averaged over the period of 2008–2017 for each EU country. The MPK is calculated using $\alpha_k y/k$, where $\alpha_k = 1 - \alpha_l$ under constant returns to scale.

In the dynamic analysis, I calibrate the parameters to match the moments in Estonia because it has the highest concentration among the EU countries and would provide a contrast with the perfect banking competition scenario. As shown in Table 2, Estonia has an average HHI of 0.26, so N is set to 3 to match the HHI in the data.[15] The observed average labor share over 2008–2017 for Estonia is 0.58, so the capital share α_k is 0.42 under a constant-returns-to-scale Cobb-Douglas production function. Using the output-to-capital ratio (real

[15]With identical banks, HHI is simply the inverse of N. Therefore, N is calibrated to $1/0.26$, which is rounded down to the nearest integer.

GDP/real capital stock) from the Penn World Table, the MPK can be calculated using the product of α_k and the output-to-capital ratio. In the steady state, MPK equals $(R_b - 1 + \delta)$. Therefore, δ can be calibrated together with the endogenously determined R_b to match the MPK in the data.

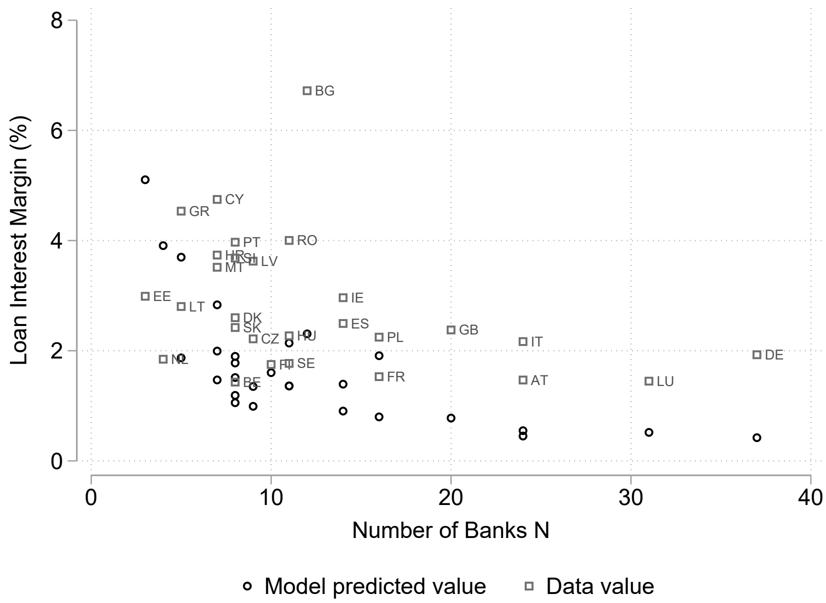
The household subjective discount factor β is calibrated to match the annualized net policy rate from the BIS database. To achieve the annualized net policy rate of 0.9% in Estonia as shown in Table 2, β is calibrated to 0.998 at a quarterly frequency, giving an annualized net policy rate of $\left(\frac{1}{0.998} - 1\right) * 4 \approx 0.9\%$. As shown in Table 2, the employed people work for 1877 hours on average in Estonia over 2008–2017. Assuming people work five days a week, 1877 working hours implies people work 7.2 hours a day on average, and hence the labor time normalized by 24 hours (i.e., steady state labor l) is around 0.3. The relative utility weight on leisure time ϕ is set to 1.8 to achieve a steady state labor l of around 0.3.

The other parameters are set to the commonly used values in the literature. The gross inflation target π is set to one. The elasticity of substitution among differentiated retail goods ϵ is chosen to be 6, to generate a final good price markup x over the wholesale good of 20% ($x = \frac{\epsilon}{\epsilon-1}$) in this zero-inflation steady state. The probability θ of retailers keeping prices fixed in each period is set at 0.75 to give a price rigidity of $\frac{1}{1-0.75} = 4$ quarters on average. In the baseline analysis, I calibrate the investment adjustment cost χ to be 0. Monetary policy responds to the deviation of the gross inflation rate from the inflation target π, where the feedback coefficient on inflation κ_π is set to 1.5 and the interest rate smoothing parameter ρ_r is set to 0.8. In the baseline analysis, the feedback coefficient on output deviation κ_y is set to 0 for simplicity of interpretation. The results are robust to a positive κ_y.

Using the calibrated parameters, the annualized loan interest margin in Estonia would be 5.1%. Applying the same approach to calibrate the parameters for the other EU countries by matching the moments in Table 2 and setting the other parameters the same as discussed above, I can obtain the model predicted loan interest margin for each country and compare with their data counterparts across countries.

Figure 1 plots the loan interest margins predicted by the model and in the data for each country against the calibrated N for each EU country. Each N corresponds to a country with a given level of HHI from the data. As can be seen, the model predicted loan interest margins align well with their data counterpart and can replicate the negative relationship between the loan interest margins and the number of banks (inverse of HHI with identical banks), which is also shown in Table 1. When the banking sector is more competitive under a larger number of banks, banks' market power is lower and thus the loan interest margin is smaller. The model predicted loan interest margins can also replicate the positive empirical relationship between the loan interest margin and MPK across countries.

Figure 1: Loan Interest Margins across EU Countries with Different Bank Concentration



Data sources: ECB, Bulgarian central bank website, BIS
Note: This figure plots the model predicted annualized loan interest margins and their data counterparts against the number of banks that is calibrated to match the HHI in each country. Each point in the figure corresponds to an EU country. The data values of the loan interest margins are averaged over the period of 2008 to 2017.

Section 4 studies the dynamics of the loan interest margin and its impact on the transitory dynamics after three types of shocks: persistent capital quality shocks, and one-time productivity shocks and monetary policy shocks. The standard deviation for the three types of shocks is set to 0.005, $\sigma_\tau = \sigma_r = \sigma_z = 0.005$. Following Gertler and Karadi (2011), the persistence of the shock ψ_τ is set to 0.66.

4 Dynamic Analysis

The key differentiating factor between perfect and imperfect banking competition is the endogenous loan interest margin. As discussed in Section 2.6, with perfect banking competition and costless intermediation, the loan interest margin is zero and remains constant over the business cycle. In contrast, with imperfect banking competition, banks endogenously adjust their loan interest margin in response to shocks, which in turn affects the aggregate fluctuations.

In the following sections, I investigate how the endogenous loan interest margin evolves over time after a capital quality shock, a productivity shock, and a monetary policy shock, respectively. In particular, I focus on how different shocks affect the loan interest margin through the mechanism discussed in Section 2.6.2, i.e., the dynamics of the expected MPK. After each type of shock, I show how the transitory dynamics of the aggregate variables differ among different levels of banking competition due to the endogenous loan interest margin.

I look at three types of banking competition by varying the number of banks N: perfect banking competition with N approaching infinity, oligopoly banking competition with the calibrated $N = 3$ discussed in Section 3.2, and monopoly banking competition with N set to one. Different types of banking competition would give different steady states due to the steady state loan interest margin being different. To compare the aggregate outcomes under different types of banking competition, I assume that the entire steady steady profit of the banking sector under imperfect banking competition is taxed and transferred to households, so that the steady states are identical across different types of banking competition.[16]

There are three main findings. First, after negative shocks such as a negative capital quality shock, a contractionary monetary policy shock, and a negative productivity shock, the expected MPK tends to increase, which makes the loan demand more inelastic and thus raises the loan interest margin above its steady state under imperfect banking competition. A higher loan interest margin implies a higher borrowing cost and reduces firms' capital and thus output by more relative to the case of perfect banking competition.

Second, the expected MPK tends to increase when there are exogenous or endogenous upward forces on the expected user cost of capital, such as the rise in the real interest rate after a contractionary monetary policy shock, the reduction in the resale value of capital after a negative capital quality shock, and the endogenous rise in the real interest rate after a negative productivity (supply) shock. A higher expected user cost of capital reduces firms' capital to below its steady state value and thus raises the expected MPK. As the expected MPK rises above its steady state, firms would want to purchase more capital, which makes their capital and loan demand more inelastic. Banks with market power then respond to the more inelastic loan demand by charging a higher loan interest margin, which in turn amplifies the output drop.

Third, the magnitude of the amplification effect depends on the extent to which banks internalize the effects of the loan rate on the economy. In an extension in Section 4.4, I assume that banks not only internalize the direct impact of the loan rate on the firm's capital demand, but also internalize the indirect impact of the loan rate on the capital demand through the labor market changes. In this case, I find that the steady state loan

[16]More specifically, the tax rate $\tau \in (0,1)$ is set to ensure that the steady state bank profit after tax $[R_b(1-\tau) - R]b$ becomes zero under Cournot banking competition. The implied tax rate is $\tau = \frac{R_b - R}{R_b}$.

interest margin and thus the amplification effect on aggregate fluctuations would be smaller. This is because when banks internalize more effects of the loan rate on the economy, a higher loan rate would have a larger impact on the firm's loan demand, making the loan demand more elastic.

4.1 Capital Quality Shock

This section introduces an unexpected persistent capital quality shock, where the white noise term $e_{\tau,t}$ in (8) is reduced by 0.5 percentage points at the beginning of period 1. A negative capital quality shock directly lowers the output (6). The focus here is how different types of banking competition would affect the magnitude of the output drop. Figure 2 shows the transitional dynamics of aggregate variables under three types of banking competition: perfect banking competition, oligopoly competition with the calibrated N, and monopoly competition with N set to one.

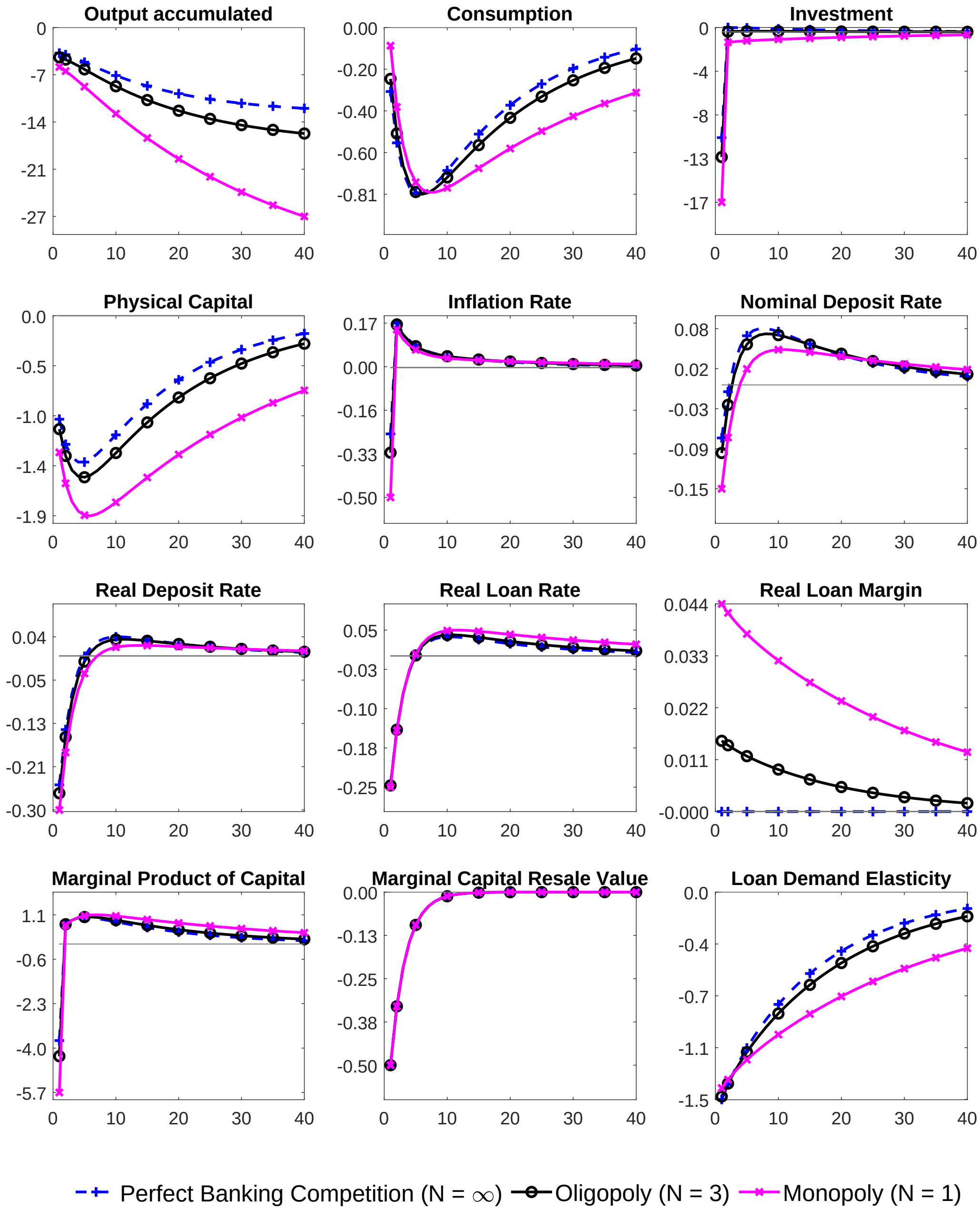
As shown in Figure 2, while the initial drop in output is of a similar magnitude among different types of banking competition, the persistence of the output drop is much larger under imperfect banking competition relative to perfect banking competition. For example, under oligopoly banking competition, the accumulated output drop relative to the steady state is around 15.3% in period 40, which is 31% larger than that under the perfect banking competition (11.7%). Under the extreme case of monopoly banking competition, the accumulated output drop in period 40 is around 134% larger compared to the perfect banking competition.

The difference in output responses is driven by the change in the real loan interest margin, which is the key differentiating variable between different types of banking competition. With perfect banking competition, the loan interest margin $(R_{b,t} - R_t)$ stays at a constant zero, whereas it endogenously rises under the imperfect banking competition. This is because the loan demand elasticity decreases after the shock, as shown in Figure 2, and banks with market power will take advantage of the lower loan demand elasticity by raising their loan interest margin.[17]

As discussed in Section 2.6.2, the change in the expected MPK is important for understanding how the loan demand elasticity changes. When the expected MPK is higher, firms are more willing to borrow to purchase new capital, making their capital and thus loan demand less sensitive to the loan rate. In this model, firms demand capital up to the point where the expected MPK equals the expected user cost of capital. Consequently, factors in-

[17] Under perfect banking competition, despite the market loan demand becoming more inelastic, each bank faces a perfectly elastic loan demand and takes the equilibrium loan rate as given. Therefore, the loan interest margin remains constant at zero under perfect banking competition.

Figure 2: Impulse Responses to a Negative Capital Quality Shock



Note: The horizontal axis shows quarters after a negative capital quality shock of 0.5 percentage points at the beginning of period 1. The vertical axis shows the percentage deviation from the steady state for variables other than the interest rates and the loan margin, which are expressed in deviations from the steady state in percentage points. The marginal product of capital is $\alpha_k z_t n_t^{\alpha_l} \tau_t^{\alpha_k} k_{t-1}^{\alpha_k - 1}$, the marginal resale value of capital is $q_t(1-\delta)\tau_t$, and the loan demand elasticity is calculated using (33).

fluencing the expected MPK—either directly or indirectly via changes in the expected user cost of capital—can drive the dynamics of the expected MPK.

After a negative capital quality shock, there are two main forces that determine the dynamics of the MPK. First, similar to a negative productivity shock, a lower capital quality τ_t directly reduces the MPK. This explains why MPK decreases in the initial period, as shown in Figure 2.[18] Due to the persistence $\psi_\tau > 0$, this downward pressure on the MPK persists over time. Second, the negative capital quality shock also reduces the expected resale value of capital $q_{t+1}\tau_{t+1}(1-\delta)$, which tends to raise the expected MPK by pushing up the expected user cost of capital.[19] The second force dominates and thus the MPK rises from period 2 onwards, resulting in a higher loan interest margin.[20]

The increase in the real loan margin distorts the firm's borrowing decision and the household's consumption-saving decision relative to the perfect banking competition benchmark. A higher real loan margin implies a higher borrowing cost which reduces the firm's investment in capital by more. In addition, the household would want to save less due to the distorted expected return from saving. By saving more today, instead of getting the expected return on capital under perfect banking competition, households only get a fraction $\frac{1}{\mu_t}$ of that expected return under imperfect banking competition, where $\mu_t = R_{b,t}/R_t$ is the loan rate markup. This explains why the fall in consumption in period 1 is smaller under imperfect banking competition in Figure 2.

Since the change in output depends on the changes in consumption and investment, the opposite effects of the higher real loan margin on consumption and investment during the initial periods roughly cancel out, leaving the initial output drop almost the same under different types of banking competition. However, the effect of lower investment is amplified through the capital accumulation process, leading to a more persistent reduction in output under imperfect banking competition.

4.2 Monetary Policy Shock

This section investigates the impacts of banking competition after an unexpected one-time contractionary monetary policy shock, where the white noise term $e_{r,t}$ in the Taylor rule is

[18] Note that this change in MPK in the initial period does not affect the loan demand elasticity or the loan interest margin which depend on the expected future MPK.

[19] Note that in the baseline calibration, $\chi = 0$ so that capital price q stays constant at one. Therefore, the change in the resale value of capital here is only driven by the exogenous force on τ. When $\chi > 0$, the capital price endogenously changes, but this endogenous force is small compared to the exogenous force on τ, so it does not affect the results here.

[20] While a one percentage change in τ_t leads to an α_k percentage change in $\text{MPK}_{t+1} = z_{t+1}\alpha_k(\tau_{t+1}k_t)^{\alpha_k} l_{t+1}^{\alpha_l}$, it leads to a one percentage drop in the resale value of capital. Therefore, the upward force on the resale value of capital dominates the direct downward force on the expected MPK.

raised by 50 basis points at the beginning of period 1. Figure 3 shows that the accumulated output drop is larger under imperfect banking competition relative to perfect banking competition. Under oligopoly banking competition, the accumulated drop in output in period 40 is around 20% from the steady state, which is 15% larger than that under the perfect banking competition (17.4%). Under the monopoly banking competition, the accumulated output drop in period 40 is around 28.7%, which is 65% larger relative to perfect banking competition.

The dynamics of the expected MPK is important for understanding the rise in the loan interest margin and the resulting more persistent output drop under imperfect banking competition. As shown in Figure 3, with perfect banking competition, the MPK first decreases in the initial period after the contractionary monetary policy shock. This is due to the drop in equilibrium labor n_t, given that capital k_{t-1} is predetermined and there are no exogenous changes in τ_t or z_t. This initial drop in the MPK does not matter because the loan demand elasticity and the loan interest margin depend on $\mathbb{E}_t \text{MPK}_{t+1}$ rather than MPK_t.

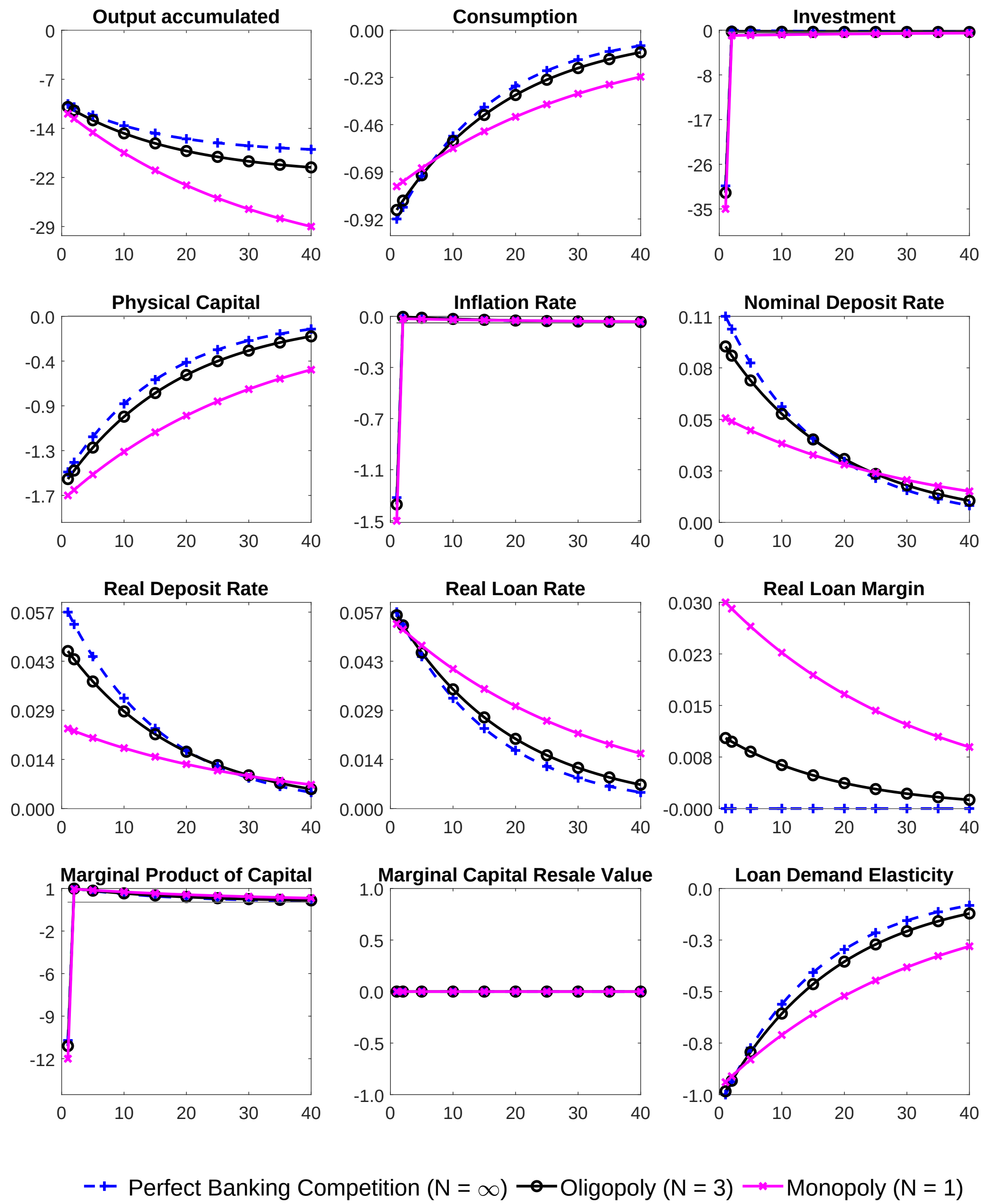
As shown in Figure 3, the future MPK rises from period 2 onwards due to the rise in the real interest rate after the contractionary monetary policy shock. In addition to the exogenous shock, the transition dynamics of consumption also contributes to the rise in the real interest rate. That is, to facilitate consumption to rise towards its steady state, the real deposit rate needs to stay above its steady state.[21] As the expected MPK is higher, the market loan demand elasticity is lower. Under perfect banking competition, despite the changes in the market loan demand elasticity, each bank still faces a perfectly elastic demand, so they would not respond to this changing market loan demand elasticity and the real loan margin remains at zero. However, with imperfect banking competition, banks with market power would take advantage of the more inelastic loan demand by charging a higher loan interest margin. This in turn distorts the firm's borrowing decision and the household's saving decision, as discussed in Section 4.1, which leads to a more persistent output drop.

Unlike the persistent capital quality shock, here there is no change in the resale value of capital as τ_t stays at one without the capital quality shock and capital price q_t also stays at one under $\chi = 0$.[22] Therefore, the main upward force on the expected MPK here is the rise in the real interest rate, which in turn raises the expected user cost of capital and the

[21] The general equilibrium dynamics of the real interest rate reflect the intertemporal substitution of consumption. As consumption rises towards the steady state (i.e., $c_{t+1} > c_t$), the real interest rate is high during this transition to induce households to save for future consumption.

[22] With investment adjustment cost (i.e., $\chi > 0$), the capital price drops initially and then rises above its steady state to facilitate the recovery of investment. This tends to raise the expected resale value of capital, lowering the expected user cost of capital and the expected MPK. Therefore, with this endogenous change in capital price, the amplification effect of the loan interest margin after the contractionary monetary policy shock can be smaller.

Figure 3: Impulse Responses to a Contractionary Monetary Policy Shock



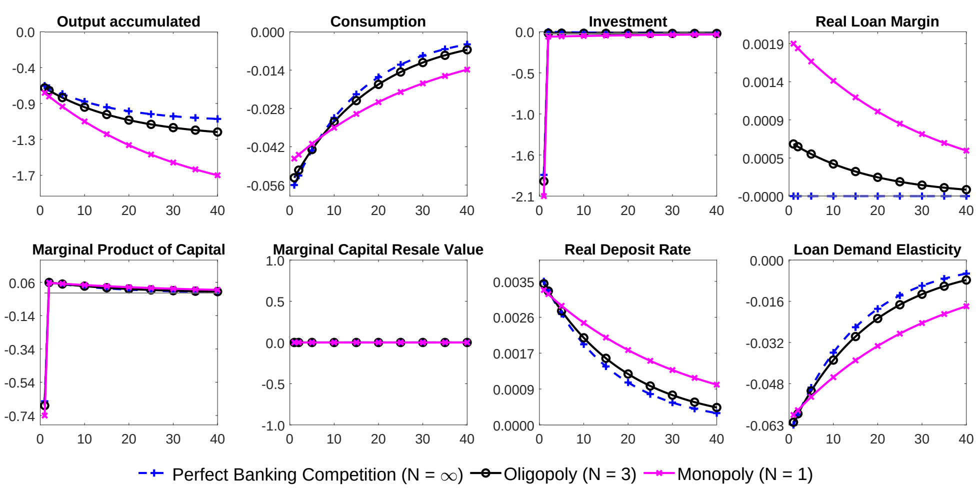
Note: The figure shows the impulse responses of aggregate variables after a one-time contractionary monetary policy shock. The horizontal axis shows quarters after the contractionary monetary policy shock of 50 basis points at the beginning of period 1. The vertical axis shows the percentage deviation from the steady state for variables other than the interest rates and the loan margin, which are expressed in deviations from the steady state in percentage points. The marginal product of capital is $\alpha_k z_t n_t^{\alpha_l} \tau_t^{\alpha_k} k_{t-1}^{\alpha_k - 1}$, the marginal resale value of capital is $q_t(1-\delta)\tau_t$, and the loan demand elasticity is calculated using (33).

expected MPK. The higher real interest rate is driven by both the contractionary monetary policy shock and the transition dynamics of the consumption.

4.3 Productivity Shocks

This section studies a one-time negative productivity shock where the white noise term $e_{z,t}$ (7) is reduced by 0.5 percentage points at the beginning of period 1. Figure 4 shows that the output drop under imperfect banking competition is also more persistent after the negative productivity shock. The accumulated output drop in period 40 is around 1.2% under oligopoly banking competition, which is around 10% larger than the accumulated output drop of 1.1% under perfect banking competition. In the extreme case of a monopoly bank, the accumulated output drop is around 1.8%, which is around 64% larger compared to the perfect banking competition.

Figure 4: Impulse Responses to a Negative One-time Productivity Shock



Note: The figure shows the impulse responses of aggregate variables after a one-time negative productivity shock. The horizontal axis shows quarters after the negative productivity shock of 0.5 percentage points at the beginning of period 1. The vertical axis shows the percentage deviation from the steady state for variables other than the interest rates and the loan margin, which are expressed in deviations from the steady state in percentage points. The marginal product of capital is $\alpha_k z_t n_t^{\alpha_l} \tau_t^{\alpha_k} k_{t-1}^{\alpha_k - 1}$, the marginal resale value of capital is $q_t(1-\delta)\tau_t$, and the loan demand elasticity is calculated using (33).

To understand why the output drop after the negative productivity shock is more persistent under imperfect banking competition, we first need to understand how the productivity shock affects the dynamics of the expected MPK, which in turn drives the loan demand elasticity and the real loan margin. The exogenous one-time negative productivity shock directly reduces the MPK in the initial period through a lower z_t. As discussed before, the initial drop in the MPK does not matter because the real loan margin depends on the expected future MPK.

As shown in Figure 4, the MPK increases from period 2 onwards driven by an endogenously higher real interest rate. This is different from the negative capital quality shock or the contractionary monetary policy shock that can exogenously raise the expected user cost of capital and thus the expected MPK. In contrast, here the main upward force on the expected MPK is the general equilibrium dynamics of the real interest rate, which reflects the intertemporal substitution of consumption. After the negative productivity shock, as consumption rises toward its steady state (i.e., $c_{t+1} > c_t$), the real deposit rate gradually decreases but remains above its steady state to induce households to save for future consumption. As shown in Figure 4, under perfect banking competition, the real deposit rate increases, which raises the expected user cost of capital and thus the expected MPK. This in turn leads to a lower loan demand elasticity and a higher real loan margin.[23]

Compared to the capital quality shock, the impacts of imperfect banking competition on aggregate fluctuations are smaller after the productivity shock and the monetary policy shock. This is because the main forces that drive the dynamics of the MPK and thus the real loan margin are different. The negative capital quality shock exerts a strong downward force on the expected resale value of capital, which raises the expected user cost of capital and thus the expected MPK. However, this force is absent after the negative productivity shock or the contractionary monetary policy shock, where the only upward forces on the expected MPK are the endogenous rise in the real interest rate (that reflects the intertemporal substitution of consumption) as well as the exogenous initial increase in the real interest rate due to the contractionary monetary policy shock.

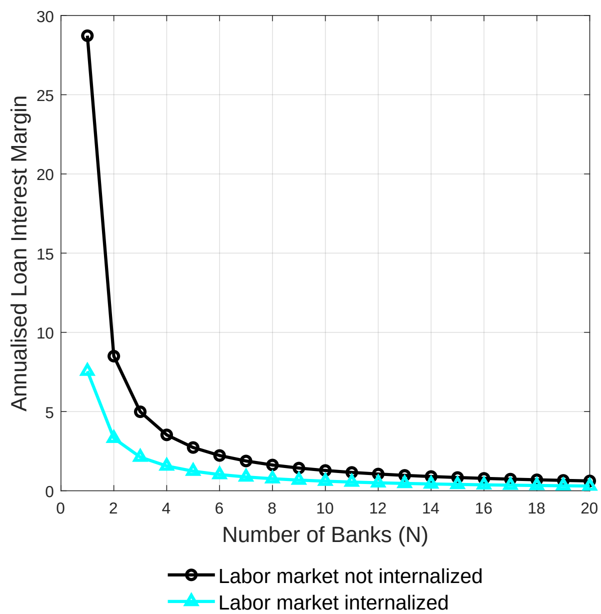
4.4 Extension: Banks Internalize Labor Market Outcomes

In this section, I show that the magnitude of the amplification effect on aggregate fluctuations depends on the extent to which banks internalize the effects of the loan rate on the economy. Different from the baseline analysis above, here I assume banks with market power would internalize not only the direct impact of the loan rate on the firm's capital demand, but also the indirect effect on capital demand through the equilibrium labor. As banks internalize more effects of the loan rate on the economy, it implies that a higher loan rate would have a bigger impact on the firm's capital and thus loan demand, making the loan demand more

[23]Given this negative productivity shock is a one-time shock, there is no exogenous downward force on the expected MPK. So the upward force dominates and the real loan margin rises immediately. However, if the negative productivity shock were persistent with $\psi_z = 0.9$, for instance, this persistent downward force on the expected MPK can be strong enough to dominate during the early periods. In this case, the real loan margin can decrease initially.

elastic. The higher loan demand elasticity leads to a lower steady state loan interest margin and also a smaller amplification effect on the aggregate fluctuations.

Figure 5: Steady State Loan Margins With and Without Labor Market Internalization



Note: This figure plots the steady state annualized loan interest margins (%) against the number of banks N under two different model specifications: (1) banks with market power only internalize the direct effect of the loan rate on the firm's capital demand and do not internalize the indirect effect on capital demand through the labor market; (2) banks also internalize the indirect effect of the loan rate on capital demand through the labor market.

To account for the labor market internalization when deriving the capital demand elasticity, we first need to know how the equilibrium labor responds to the loan rate. By log-linearizing the labor demand (12) and labor supply (4), it is shown in Appendix A.3 that the percentage change in the equilibrium labor is:

$$\tilde{l}_t = \frac{1}{\gamma_t + \alpha_k}(\tilde{z}_t + \alpha_k \tilde{\tau}_t + \alpha_k \tilde{k}_{t-1} - \tilde{x}_t - \tilde{c}_t) \tag{36}$$

where $\tilde{X}_t \equiv \frac{X_t' - X_t}{X_t}$ denotes the percentage change in X around X_t and $\gamma_t \equiv \frac{l_t}{1-l_t}$ is the inverse Frisch labor supply elasticity. As can be seen from (36), a higher loan rate $R_{b,t}$ that reduces k_t can in turn reduce the equilibrium labor l_{t+1}. Substituting (36) into (32), one can obtain:

$$\tilde{k}_t = -\frac{1}{1-\alpha_k}\frac{\mathbb{E}_t\gamma_{t+1} + \alpha_k}{\mathbb{E}_t\gamma_{t+1}}\frac{\mathbb{E}_t[\frac{R_{b,t}q_t}{\pi_{t+1}}]}{\mathbb{E}_t\mathrm{MPK}_{t+1}}(\tilde{R}_{b,t} + \tilde{q}_t - \mathbb{E}_t\tilde{\pi}_{t+1}) + \mathbb{E}_t\tilde{\Phi}_{t+1} \tag{37}$$

where $\mathbb{E}_t\tilde{\Phi}_{t+1} \equiv \mathbb{E}_t\frac{1}{\gamma_{t+1}}(\tilde{z}_{t+1}+\alpha_k\tilde{\tau}_{t+1}-\tilde{x}_{t+1}-\tilde{c}_{t+1})+\mathbb{E}_t\frac{\gamma_{t+1}+\alpha_k}{\gamma_{t+1}}\tilde{\Omega}_{t+1}$ is a collection of exogenous shocks and aggregate prices, as well as a consumption term $\tilde{c}_{t+1}$. Note that $\tilde{c}_{t+1}$ is not directly affected by $R_{b,t}$ as the household's consumption-saving decisions are based on the deposit rate or the policy rate R_t set by the central bank, rather than the loan rate. Therefore, the loan demand elasticity, or equivalently, the capital demand elasticity, is implied by the term in front of $\tilde{R}_{b,t}$ in (37), which can be rewritten as:

$$\text{PED}_t = \frac{1}{1-\alpha_k}\frac{\mathbb{E}_t\gamma_{t+1}+\alpha_k}{\mathbb{E}_t\gamma_{t+1}}\left(1+\frac{\mathbb{E}_t[q_{t+1}(1-\delta)\tau_{t+1}]}{\mathbb{E}_t\text{MPK}_{t+1}}\right) \tag{38}$$

Comparing with (33), the additional term in PED_t is $\frac{\mathbb{E}_t\gamma_{t+1}+\alpha_k}{\mathbb{E}_t\gamma_{t+1}}$, which depends on the inverse labor supply elasticity γ_{t+1}. Since this additional term is greater than one, it can be seen that the steady state PED will be higher, leading to a lower steady state loan interest margin. Figure 5 shows that for a given level of N, the steady state loan interest margin when labor market is internalized is lower than that without labor market internalization.

In addition, (38) shows that when the labor supply elasticity is lower (i.e., the inverse labor supply elasticity γ_{t+1} is higher), the loan demand becomes more inelastic. Intuitively, this is because when the labor supply is less elastic, the equilibrium labor $\tilde{l}_{t+1}$ is also less responsive to $\tilde{k}_t$, which can also be seen in (36).[24] In this case, the impact of a higher loan rate on capital demand transmits less into the labor market. Since the resulting decline in labor is smaller, the feedback effect from the labor market that can further reduce the capital demand is also weaker. Therefore, the drop in capital demand in response to a higher loan rate is smaller compared to the case when the feedback from the labor market is stronger. In other words, the capital and loan demand would become more inelastic.

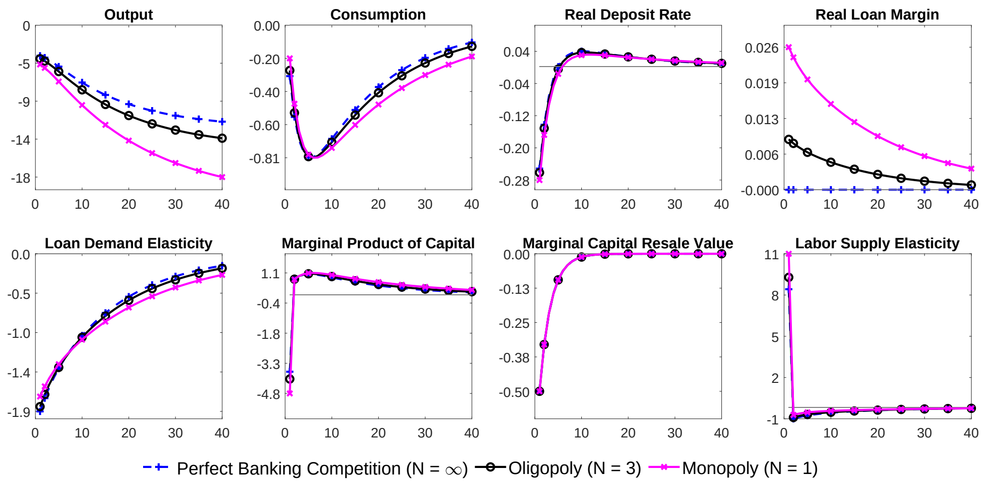
As shown in Figure 6, the labor supply elasticity decreases (i.e., $1/\tau_{t+1}$ decreases) from period 2 onwards. This implies a more inelastic capital and loan demand because the transmission of a higher loan rate into reducing the equilibrium labor and thus capital is weaker. Together with the rise in the expected MPK, the market loan demand elasticity decreases. Banks with market power under imperfect banking competition then respond to this changing market loan demand elasticity by raising their loan interest margin, which makes the output drop more persistent.

Compared with Figure 2, Figure 6 shows that the impacts of imperfect banking competition on aggregate fluctuations are smaller when banks internalize the impact of the loan rate on the labor market. This is due to the higher steady state PED and the lower steady state loan interest margin shown above.[25] If N were calibrated to 1.5, which would give roughly

[24] In the extreme case when the labor supply is perfectly inelastic (i.e., $\gamma_{t+1} \to \infty$), $\tilde{l}_{t+1}$ is not responsive to $\tilde{k}_t$.

[25] It can be shown that the percentage change in the loan interest margin decreases in the steady state

Figure 6: Impulse Responses to a Negative Capital Quality Shock When Banks Internalize the Impact of Loan Rate on Labor Market



Note: The figure shows the impulse responses of aggregate variables after a persistent negative capital quality shock in an extension where banks are assumed to internalize the impact of loan rate on the equilibrium labor as well as the direct impact of the loan rate on the firm's capital demand. The horizontal axis shows quarters after the negative capital quality shock shock of 0.5 percentage points at the beginning of period 1. The vertical axis shows the percentage deviation from the steady state for variables other than the interest rates and the loan margin, which are expressed in deviations from the steady state in percentage points. The marginal product of capital is $\alpha_k z_t n_t^{\alpha_l} \tau_t^{\alpha_k} k_{t-1}^{\alpha_k - 1}$, the marginal resale value of capital is $q_t(1-\delta)\tau_t$, and the loan demand elasticity is calculated using (38).

the same steady state loan interest margin as in the baseline analysis when $N = 3$, then the impacts on transitory dynamics are similar to the baseline case.

5 Conclusions

This paper studies how imperfect banking competition affects aggregate fluctuations by incorporating a Cournot banking sector into an otherwise standard DSGE framework. In doing so, the paper unveils a new mechanism that explains the time-varying loan interest margin under imperfect banking competition. The mechanism works through the dynamics of the expected MPK. Intuitively, firms would be more willing to borrow to purchase new capital when the expected return on capital is higher. This tends to make the firm's capital and thus loan demand less sensitive to the loan rate. Banks with market power then take advantage of the more inelastic loan demand by charging a higher loan interest margin.

PED by log-linearizing (31) around the steady state. Since the percentage change in the loan interest margin becomes smaller, the amplification effect on the aggregate fluctuations is also smaller.

I find that after a negative shock, the expected MPK tends to increase due to the upward forces on the expected user cost of capital, such as the rise in the real interest rate after a contractionary monetary policy shock and the reduction in the resale value of capital after a negative capital quality shock. A higher expected user cost of capital reduces firms' capital to below its steady state value and thus raises the expected MPK. Due to the higher expected MPK, firms would want to purchase more capital, which makes their capital and loan demand more inelastic. Under imperfect banking competition, banks would respond to the more inelastic loan demand by charging a higher loan interest margin, which in turn amplifies the output drop.

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Appendices

A Derivation

Section A.1 solves for the bank's problem under Cournot banking competition. Section A.2 shows the derivation for the capital demand and the elasticities of the capital and loan demand with respect to the gross loan rate. Section A.3 derives the capital demand elasticity in an extension where banks are assumed to internalize the impact of the loan rate on the labor market.

A.1 Solving Bank's Problem under Cournot Competition

Solving the profit maximization problem with respect to $b_t(j)$ gives the following first order condition:

$$E_t\left[\Lambda_{t,t+1}\frac{1}{\pi_{t+1}}\left\{\frac{\partial R_{b,t}}{\partial b_t(j)}b_t(j)+R_{b,t}-R_t\right\}\right]=0 \tag{39}$$

In a Cournot equilibrium, the total optimal loan quantity is $b_t = b_t(j)+\sum_{m\neq j} b_t(m)$ and each bank produces a share of the total quantity. Assuming banks are identical, then $b_t(j)=\frac{b_t}{N}$ in equilibrium.

Since $\frac{\partial R_{b,t}}{\partial b_t(j)}=\frac{\partial R_{b,t}}{\partial b_t}\frac{\partial b_t}{\partial b_t(j)}=\frac{\partial R_{b,t}}{\partial b_t}$ in Cournot equilibrium, the first order condition (39) can be rewritten as:

$$\mathbb{E}_t\left[\Lambda_{t,t+1}\frac{1}{\pi_{t+1}}\left\{\frac{\partial R_{b,t}}{\partial b_t}\frac{b_t}{N}+R_{b,t}-R_t\right\}\right]=0 \tag{40}$$

Given that $\Lambda_{t,t+1}>0$ and $\pi_{t+1}\equiv\frac{p_{t+1}}{p_t}>0$, (30) implies that the loan interest margin can be written as:

$$R_{b,t}-R_t=-\frac{\partial R_{b,t}}{\partial b_t}\frac{b_t}{N} \tag{41}$$

Let $\text{PED}_t \equiv -\frac{\partial b_t}{\partial R_{b,t}}\frac{R_{b,t}}{b_t}$ denote the market loan demand elasticity. Using the definition of PED, the loan interest margin can be written as:

$$R_{b,t}-R_t=\frac{1}{N}\frac{1}{\text{PED}_t}R_{b,t} \tag{42}$$

Rearrange and simplify to get:

$$R_{b,t}-R_t=\frac{1}{N\text{PED}_t-1}R_t \tag{43}$$

A.2 Elasticities of Capital and Loan Demand

Rearrange the firm's first order condition with respect to k_t (11) as:

$$\mathbb{E}_t\Lambda_{t,t+1}\left[\frac{z_{t+1}\alpha_k\tau_{t+1}^{\alpha_k}k_t^{\alpha_k-1}l_{t+1}^{\alpha_l}}{x_{t+1}}\right]=\mathbb{E}_t\Lambda_{t,t+1}\left[\frac{R_{b,t}q_t}{\pi_{t+1}}-q_{t+1}(1-\delta)\tau_{t+1}\right]\tag{44}$$

Let $\tilde{X}_t \equiv \frac{X_t'-X_t}{X_t}$ denote the percentage deviation from the period-t value. Log-linearize the capital demand (11) around period t to get:

$$\tilde{z}_{t+1}+\alpha_k\tilde{\tau}_{t+1}+(\alpha_k-1)\tilde{k}_t+\alpha_l\tilde{l}_{t+1}-\tilde{x}_{t+1}=\frac{\frac{R_{b,t}q_t}{\pi_{t+1}}}{\mathrm{MPK}_{t+1}}(\tilde{R}_{b,t}+\tilde{q}_t-\tilde{\pi}_{t+1})-\frac{q_{t+1}\tau_{t+1}(1-\delta)}{\mathrm{MPK}_{t+1}}(\tilde{q}_{t+1}+\tilde{\tau}_{t+1})\tag{45}$$

Rearrange to get:

$$\tilde{k}_t=-\frac{1}{1-\alpha_k}\frac{\mathbb{E}_t[\frac{R_{b,t}q_t}{\pi_{t+1}}]}{\mathbb{E}_t\mathrm{MPK}_{t+1}}(\tilde{R}_{b,t}+\tilde{q}_t-\mathbb{E}_t\tilde{\pi}_{t+1})+\mathbb{E}_t\tilde{l}_{t+1}+\mathbb{E}_t\tilde{\Omega}_{t+1}\tag{46}$$

where $\mathbb{E}_t\mathrm{MPK}_{t+1}\equiv\mathbb{E}_t\left[\frac{z_{t+1}\alpha_k\tau_{t+1}^{\alpha_k}k_t^{\alpha_k-1}l_{t+1}^{\alpha_l}}{x_{t+1}}\right]=\mathbb{E}_t\left[\frac{R_{b,t}q_t}{\pi_{t+1}}-q_{t+1}(1-\delta)\tau_{t+1}\right]$ and $\tilde{\Omega}_{t+1}$ is defined to collect all the other terms in (45), which consists of exogenous shocks and aggregate prices:

$$\mathbb{E}_t\tilde{\Omega}_{t+1}\equiv\frac{1}{1-\alpha_k}\mathbb{E}_t\left[\frac{q_{t+1}\tau_{t+1}(1-\delta)}{\mathrm{MPK}_{t+1}}(\tilde{q}_{t+1}+\tilde{\tau}_{t+1})+\tilde{z}_{t+1}+\alpha_k\tilde{\tau}_{t+1}-\tilde{x}_{t+1}\right]\tag{47}$$

As can be seen from (46), the term in front of $\tilde{R}_{b,t}$ captures the direct effect of the loan rate on the firm's capital demand. In the baseline analysis, I assume banks with market power only take into account this direct effect of the loan rate and do not internalize the indirect effects of the loan rate on the aggregate-level prices $(q_t, q_{t+1}, x_{t+1}, \pi_{t+1})$ or the equilibrium labor $\tilde{l}_{t+1}$. Appendix A.3 considers the extension where banks would also internalize the indirect effects of the loan rate on capital demand via the equilibrium labor $\tilde{l}_{t+1}$.

Consequently, the capital demand elasticity is given by the magnitude of the term in front of $\tilde{R}_{b,t}$ in (46):

$$\mathrm{PEK}_t\equiv-\frac{\partial k_t}{\partial R_{b,t}}\frac{R_{b,t}}{k_t}=\frac{1}{1-\alpha_k}\frac{\mathbb{E}_t[\frac{R_{b,t}q_t}{\pi_{t+1}}]}{\mathbb{E}_t\mathrm{MPK}_{t+1}}=\frac{1}{1-\alpha_k}\left(1+\frac{\mathbb{E}_t[q_{t+1}(1-\delta)\tau_{t+1}]}{\mathbb{E}_t\mathrm{MPK}_{t+1}}\right)\tag{48}$$

where the second equality uses $\mathbb{E}_t[\frac{R_{b,t}q_t}{\pi_{t+1}}]=\mathbb{E}_t[\mathrm{MPK}_{t+1}+q_{t+1}(1-\delta)\tau_{t+1}]$.

Given the firm's loan demand $b_t = q_t k_t$ and the assumption that banks do not internalize the impact of the loan rate on the aggregate prices such as q_t, the elasticity PED_t of the market loan demand to the gross loan rate is:

$$\text{PED}_t \equiv -\frac{\partial b_t}{\partial R_{b,t}}\frac{R_{b,t}}{b_t} = -q_t\frac{\partial k_t}{\partial R_{b,t}}\frac{R_{b,t}}{q_t k_t} = \text{PEK}_t \tag{49}$$

which is equivalent to the capital demand elasticity.

A.3 Extension: Banks Internalize Labor Market

Here, banks are assumed to internalize not only the direct effect of the loan rate on the capital demand, but also the indirect effect on the capital demand through the equilibrium labor. In this section, I first derive the equilibrium labor and then substitute it into (46) to obtain the capital demand elasticity that banks would internalize in this case.

Log-linearize the labor demand (12) to get:

$$\tilde{w}_t = \tilde{z}_t + \alpha_k\tilde{\tau}_t + \alpha_k\tilde{k}_{t-1} + (\alpha_l - 1)\tilde{l}_t - \tilde{x}_t \tag{50}$$

Log-linearize the labor supply (4) to get:

$$\frac{l_t}{1-l_t}\tilde{l}_t = \tilde{w}_t - \tilde{c}_t \tag{51}$$

Combining (50) and (51), the equilibrium labor is:

$$\tilde{l}_t = \frac{1}{\gamma_t + \alpha_k}(\tilde{z}_t + \alpha_k\tilde{\tau}_t + \alpha_k\tilde{k}_{t-1} - \tilde{x}_t - \tilde{c}_t) \tag{52}$$

where γ_t denotes $\frac{l_t}{1-l_t}$. Note that $\frac{1}{\gamma_t}$ is the Frisch labor supply elasticity, which measures how sensitive the labor supply responds to the real wage, holding the marginal utility of wealth fixed. Figure 7 plots the labor demand (50) and the labor supply (51) to show the labor market equilibrium. As can be seen, the labor demand is downward-sloping, and it shifts to the right when capital stock increases.

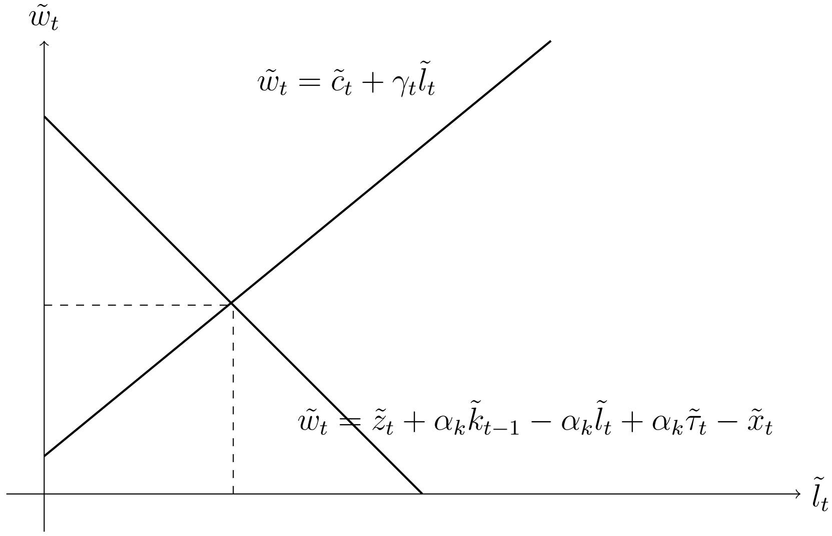
Substitute the equilibrium labor $\tilde{l}_{t+1}$ (52) into (46) and rearrange to get:

$$\tilde{k}_t = -\frac{1}{1-\alpha_k}\frac{\mathbb{E}_t\gamma_{t+1} + \alpha_k}{\mathbb{E}_t\gamma_{t+1}}\frac{\mathbb{E}_t[\frac{R_{b,t}q_t}{\pi_{t+1}}]}{\mathbb{E}_t\text{MPK}_{t+1}}(\tilde{R}_{b,t} + \tilde{q}_t - \mathbb{E}_t\tilde{\pi}_{t+1}) + \mathbb{E}_t\tilde{\Phi}_{t+1} \tag{53}$$

where $\tilde{\Phi}_{t+1}$ is a collection of exogenous shocks and aggregate prices:

$$\mathbb{E}_t\tilde{\Phi}_{t+1} \equiv \mathbb{E}_t\frac{1}{\gamma_{t+1}}(\tilde{z}_{t+1} + \alpha_k\tilde{\tau}_{t+1} - \tilde{x}_{t+1} - \tilde{c}_{t+1}) + \mathbb{E}_t\frac{\gamma_{t+1} + \alpha_k}{\gamma_{t+1}}\tilde{\Omega}_{t+1} \tag{54}$$

Figure 7: Labor Market Equilibrium



as well as a consumption term $\tilde{c}_{t+1}$. Note that $\tilde{c}_{t+1}$ is not directly affected by loan rate $R_{b,t}$ as households make consumption-saving decisions based on the deposit rate R_t. $\tilde{\Omega}_{t+1}$ is shown in (47).

Here, the capital demand elasticity considered by banks is implied by the magnitude of the term in front of $\tilde{R}_{b,t}$ in (53):

$$\mathrm{PEK}_t = \frac{1}{1-\alpha_k} \frac{\mathbb{E}_t \gamma_{t+1} + \alpha_k}{\mathbb{E}_t \gamma_{t+1}} \frac{\mathbb{E}_t[\frac{R_{b,t} q_t}{\pi_{t+1}}]}{\mathbb{E}_t \mathrm{MPK}_{t+1}} = \frac{1}{1-\alpha_k} \frac{\mathbb{E}_t \gamma_{t+1} + \alpha_k}{\mathbb{E}_t \gamma_{t+1}} \left(1 + \frac{\mathbb{E}_t[q_{t+1}(1-\delta)\tau_{t+1}]}{\mathbb{E}_t \mathrm{MPK}_{t+1}}\right) \tag{55}$$

Comparing with (48), there is an additional term due to the labor market internalization, $\frac{\mathbb{E}_t \gamma_{t+1} + \alpha_k}{\mathbb{E}_t \gamma_{t+1}}$, in (55). Since this additional term is greater than one, the capital demand elasticity will be higher.