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Regulatory capital requirements, inflation targeting, and equilibrium determinacy

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[1]

Abstract

This paper studies the stability properties of inflation-targeting interest rate rules in an economy with regulatory capital requirements. We derive the conditions for rational expectations equilibrium determinacy in a sticky-price model augmented with the cost channel of monetary policy transmission. We find that when tightening Basel II-type capital regulations, strict inflation targeting leads to significant expansions in regions of determinacy. This result is attributed to the supply side of credit markets, and especially to the procyclical nature of bank leverage and the restricted interest rate pass-through. However, when banks maintain capital ratios beyond the required thresholds, strict inflation targeting suffers from considerable shrinking regions of determinacy. Moreover, excessive bank capital holdings may give rise to self-fulfilling business cycles. The availability of countercyclical capital buffers, as proposed by Basel III, and/or a flexible inflation targeting regime offer an antidote to these problems.

Keywords Equilibrium determinacy; Inflation targeting; Monetary policy; Regulatory capital requirements

JEL Classification: E44; E52; E58; G28

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1 Introduction

The global financial crisis (GFC) has challenged perceptions of the traditional roles of monetary policy and financial regulation. In the aftermath of the GFC, there is an ongoing debate on whether monetary and macroprudential policies are closely interconnected (for a recent review of these interactions, see Smets 2014; Lubis et al. 2019) or should they be separated in both goals and authorities (Vollmer 2022). Despite the increasing body of literature on the interaction of regulatory capital requirements with monetary policy (Agénor et al. 2013; Angeloni and Faia 2013; Angelini et al. 2014; Rubio and Carrasco-Gallego 2016; Tayler and Zilberman 2016; Aliaga-Díaz, et al. 2018; Lewis and Roth 2018), this topic needs further refinement. Importantly, none of the aforementioned studies, with the notable exception of Lewis and Roth (2018), focuses on equilibrium determinacy, which constitutes the key indicator of the underlying ability of central banks to anchor expectations, and thus to avoid self-fulfilling economic fluctuations.

The main hypothesis of our study is that bank capital regulations exert a significant impact on the determinacy of rational expectations equilibrium (REE) and, thus on the robustness of the Taylor principle. Lewis and Roth (2018) argue that banks' balance sheets worsening - due to tight monetary policy - may result in a debt-disinflation spiral implying the need for passive monetary policy rules to guarantee a unique stable equilibrium. In contrast to their analysis, we place the spotlight on the role of banks' balance sheets in attaining a determinate equilibrium via the cost channel of monetary policy.[2] As such, our work deviates from Lewis and Roth (2018) in that we propose an alternative mechanism through which banks' balance sheets affect equilibrium determinacy.

The literature has shown that when the cost channel of monetary policy is at work, strict inflation targeting may shrink the determinacy regions of interest rate rules (Brückner and Schabert 2003; Surico 2008; Llosa and Tuesta 2009; Christiano et al. 2010b; Smith 2016). In particular, standard policies relying solely on the Taylor principle may not be effective in ensuring the uniqueness of the rational expectations equilibrium and an upper bound to inflation coefficient might be present. The reason is that when firms finance inputs with short-term loans (working capital loans), higher policy rates not only restrict demand but also boost marginal costs and, hence, inflation. This literature, however, either assumes that banks act as neutral conveyors of monetary policy (Christiano et al. 2005; Ravenna and Walsh 2006) or models incomplete interest rate pass-through by hinging on the coincidence of bank profits with the interest rate margin (Chowdhury et al. 2006; Hülsewig et al. 2009; Pfajfar and Santoro 2014).

Due to these restrictive assumptions, the cost channel literature has paid little attention to two empirically relevant issues. First, it ignores the role of bank costs, related to their capital requirements stemming from macroprudential regulations, in the existence of REE. However, it is likely that macroprudential policy influences the conditions that ensure equilibrium determinacy, when the cost channel matters, since macroprudential policy exerts effects on credit supply - and potentially through the cost channel - on inflation. Empirical studies confirm that higher capital requirements correspond to lower credit supply to firms (see, for example, Aiyar et al. 2014; World Bank 2019; De Jonghe et al. 2020; Fraisse and Thesmar 2020) and that tighter regulations on bank activities boost the cost of financial intermediation (Demirgüç-Kunt et al. 2004) and restrict banks' profitability (Teixeira et al. 2020). This, in turn, justifies the examination of macroprudential policy effects not only through loan financing investments (as the vast of the macro-finance literature suggests) but also via the cost channel.

Second, the shift of the policy debate towards countercyclical financial regulations is neglected in the stability discourse of the cost channel of monetary policy even though the number of countries that have used countercyclical capital requirements has significantly increased over recent years. Specifically, according to the pre-crisis consensus, time-invariant capital requirements ensure banks' solvency, and thus monetary policy mainly focuses on price stability, leaving financial stability aside. Yet, GFC has shown that fixed bank capital requirements can act as destabilizers creating a financial accelerator originating from the credit markets (Covas and Fujita 2010; Angelini et al. 2010; Repullo and Suarez 2013; Angeloni and Faia 2013). To prevent the build-up of financial imbalances, the Basel III committee proposes financial institutions to adjust their capital cyclically, building up defensive buffers in good times and reducing them in downturns.

[2] The empirical validity of the cost channel has been documented by Barth and Ramey (2001), Christiano et al. (2005), Ravenna and Walsh (2006), Gaiotti and Secchi (2006), Fernandez-Corugedo et al. (2011), Christiano et al. (2015), and Cucciniello et al. (2022).

This paper fills these voids in the literature by investigating the impact of (fixed and time-variant) bank capital regulation on the cost channel of monetary transmission and then, on equilibrium determinacy, under simple interest rate feedback rules (strict and flexible inflation targeting). Specifically, we study the local determinacy properties of the REE in the standard sticky price model by considering the case of a cost channel arising from regulatory-induced constraints on banks' balance sheets. Following Gerali et al. (2010), we assume that the supply of credit to the real economy (firms) is constrained by the availability of bank capital (as in the Basel II regulation) which can *only* be accumulated through retained earnings. That is, we rule out all other options for recapitalization. In this context, macroprudential policy gains significance, and a feedback loop emerges from the supply side of the credit market.

Our analysis shows that tightening Basel II-type capital rules significantly expands determinacy regions under all types of inflation targeting regimes. This outcome stems from the credit market's supply dynamics, specifically, the procyclicality of bank leverage and limitations in the smooth transmission of interest rate adjustments to loan rates. Particularly, our setting introduces a new channel that reinforces the (typical) demand channel of monetary policy transmission, namely the *bank-leverage* channel. Previous studies (Brückner and Schabert 2003; Surico 2008; Llosa and Tuesta 2009) focus on two strategic channels through which a locally unique REE determinacy exists in sticky price models, namely the demand and the cost channel of monetary transmission. Yet, in an economy with an imperfect competitive banking sector, there is a third mechanism that operates through the loan supply endogenous dependence on banks' leverage. The basic intuition goes as follows. Consider a situation where the central bank increases the policy interest rate in response to a non-fundamental increase in inflation. In the standard model of the cost channel, this has two opposite effects: a positive one on aggregate supply and inflation and a negative one on aggregate demand and inflation. Interestingly, the drop in output triggers even stronger deflationary pressures, as in our setting, bank capital regulations result in a procyclical bank leverage, thereby rendering the initial increase in inflation inconsistent with REE.

However, the upper bound imposed by the cost channel on inflation responses may become a cause for serious concern for the monetary authority. Specifically, when banks uphold capital ratios above required thresholds, strict inflation targeting suffers from considerably shrinking regions of determinacy. Furthermore, our findings indicate that determinacy is never attained when bank capital holdings tend to be far beyond the regulatory thersholds and the monetary authority acts as a pure inflation targeter.

These determinacy problems call into question the desirability of strict inflation stability. In this case, we argue that countercyclical bank capital requirements (the latter rise during economic upturns limiting credit growth) can help at alleviating these indeterminacy problems. The reason is that countercyclical capital requirements, such as those introduced in Basel III, promote determinacy by weakening the cost channel effect of monetary policy. We also find that in contrast to the standard cost channel model, reacting to both inflation and output gap (flexible inflation targeting) renders the economy *less* prone to indeterminacy. In particular, when the central bank also responds to output gap (i.e. it adopts flexible inflation targeting), the nominal interest rate hike is lower compared to the one related to strict inflation targeting. The smaller rise in interest rates, in turn, weakens the effect of the cost channel and enlarges the REE determinacy area. Finally, we show that the combination of Basel-III type capital regulations with flexible inflation targeting is also effective (in terms of enhancing the prospects for determinacy).

Our findings extend prior works which incorporate a stability perspective in the determinants of cost channel effects (see, *inter alia*, the studies by Chowdhury et al. (2006) and Pfajfar and Santoro (2014) regarding financial market imperfections, Smith (2016) concerning real wage rigidities, Hülsewig et al. (2009) examining loan rate staggering and Qureshi and Ahmad (2021) on trend inflation). By highlighting the role of prudential regulatory regimes in the design of monetary instruments rules, our paper is also related to two different strands of literature. The first strand is the burgeoning literature on the coordination between macroprudential policy and monetary policy that extends from the end of the so-called 'separation principle' (Christiano et al. 2010a; Curdia and Woodford 2010; Woodford 2012) and the 'integrated approach' (Adrian and Shin 2009; Mishkin 2011) to the separate approach of the policy-mix (Svensson 2012). The second strand of the literature focuses on the amplification or procyclical properties of regulatory capital requirements (Covas and Fujita 2010; Angelini et al. 2010; Agénor and da Silva 2012; Repullo and Suarez 2013; Angeloni and Faia 2013; Alvi and Williamson 2021) and their interplay with monetary policy (Angeloni and Faia 2013;

Smets 2014; Angelini et al. 2014; Tayler and Zilberman 2016; Rubio and Carrasco-Gallego 2016; Aliaga-Díaz, et al. 2018; Cecchetti and Kohler 2018; Cociuba et al. 2019).

The rest of the paper is organized as follows. Section 2 outlines the model. Section 3 explores the conditions for equilibrium uniqueness under different regulations governing banking activity, namely time-invariant bank capital requirements (Basel II), countercyclical capital buffers (Basel III), and simple interest rate feedback rules (strict and flexible inflation targeting). Section 4 concludes the paper.

2 A DSGE model of the cost channel with bank capital requirements

In this section, we set up a simple New Keynesian DSGE model with banking intermediation and a cost channel. We build on Ravenna and Walsh's (2006) model of the cost channel, where input good producers need to borrow in advance to finance production. Differently from Ravenna and Walsh's (2006), we abstract from the perfect competitive and costless banking sector that equals the loan interest rate with the policy rate. Instead, to generate endogenous loan spreads, we introduce a monopolistically competitive banking sector with bank capital requirements as in Gerali et al. (2010). The framework we use is a simplified version of Gerali et al. (2010), i.e. it abstains from i) borrowing constraints depending on the value of collateral, ii) the so-called nominal credit/debt channel as credits and debts are assumed to be indexed to current inflation, iii) household heterogeneity, i.e. patient vs. impatient households, and iv) sticky rates. This version is motivated by the desire to isolate the role of a constraint on the level of bank leverage and to introduce – in a tractable way - loan interest rate setting behavior in the standard New-Keynesian model with a cost channel.

In particular, we consider an economy consisting of four different sectors: a household sector, a production sector composed of manufacturing and retail firms, a banking sector, and a monetary authority. Households make consumption-saving and labor-leisure decisions to maximize their expected lifetime utility. Monopolistically competitive retail firms subject to Calvo-type nominal rigidities produce final consumption goods using intermediate goods. Manufacturing firms produce intermediate goods with labor as the only input. These firms use a composite of imperfectly substitutable heterogeneous loans provided by all banks, to finance working capital needs; the wage bill has to be paid at the beginning of the period before sales revenues are realized (Christiano et al. 2010b). Concerning the banking sector, banks use households' savings (deposits) and bank capital which is accumulated out of retained earnings to provide loans in a monopolistically competitive market. In contrast, banks are perfectly competitive in the deposit market (i.e. the interest rate on deposits equals the policy rate). Moreover, banks have an exogenous target leverage ratio v due to prudential regulation and it pays a cost for deviating from that target k_{kb}. As in Gerali et al. (2010), the existence of this target is a simple shortcut for studying the implications and costs of regulatory capital requirements. The target implies that bank leverage affects loan rates and the emergence of a financial accelerator rooted in the supply side of credit.

2.1.Households

The economy is populated by a continuum of infinitely lived homogenous households indexed by h on the unit interval [0,1]. We assume the following standard form for the lifetime utility function:

$$E_t \sum_{t=0}^{\infty} \beta^t \left[\frac{\left(C_{h,t}\right)^{1-\sigma}}{1-\sigma} - \frac{\left(L_{h,t}\right)^{1+\varphi}}{1+\varphi} \right] \qquad (1)$$

where E_t is the rational expectations operator conditional on the state of nature at date t, $\beta^t \in (0, 1)$ is the subjective discount factor for the typical household, $\sigma > 0$ is the inverse intertemporal elasticity of substitution, and $\varphi \geq 0$ is the inverse Frisch elasticity. The preferences of the representative household are defined over hours supplied to the manufacturing production sector $L_{h,t}$ in a Walrasian-type labor market and a standard consumption bundle $C_{h,t}$ obtained aggregating in the Dixit-Stiglitz form the quantities consumed of each good variety i (equation (2)). Parameter $\varepsilon > 1$ is represents the elasticity of substitution among good varieties.

$$C_{h,t} = \left[\int_0^1 C_{h,t}(i)^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}} \tag{2}$$

The h-th household faces a sequence of budget constraints in any given period.

$$\int_0^1 P_t(i)C_{h,t}(i)di + D_{h,t} + M_{h,t+1} \leq W_t L_{h,t} + P_t DIV_{h,t} + P_t DIV_{h,t}^{FI} + R_t D_{h,t} + M_{h,t} - P_t T_t \tag{3}$$

During period t, the household supplies labor $L_{h,t}$ to manufacturing firms receiving real income from wages W_t and pays lump-sum taxes T_t. $DIV_{h,t}$ and $DIV_{h,t}^{FI}$ are dividends stemming from ownership in (manufacturing and retail) firms and financial intermediaries, respectively. That is, $DIV_{h,t} = \int_0^1 DIV_{h,t}(j)dj + \int_0^1 DIV_{h,t}(i)di$ and $DIV_{h,t}^{FI} = \int_0^1 DIV_{h,t}^{FI}(x)dx$. The typical household can also save through accessing a competitive market for bank deposits $D_{h,t}$, where $D_{h,t} = \int_0^1 D_{h,t}(x)dx$. The assumption of intra-period deposits (i.e., deposits are paid back in the same period) ensures that there will not appear real balance frictions related to consumption in the money market. Deposits are remunerated at a rate equal to the gross riskless nominal interest rate on deposits paid by all banks. We assume the Central Bank sets R_t directly according to a monetary policy rule to be specified. M_{t+1} are money holdings carried over to period $t+1$. As the typical household uses *only* money balances to transfer resources intertemporally to smooth consumption, we also assume the presence of a cash-in-advance constraint. This guarantees that in each period the gross deposit rate (policy rate) would be different than unity. According to equation (4) the typical household needs to allocate labor income and money balances for consumption *net* of the deposits it has decided to allocate to the banking sector. This specification (letting labor income enter the cash-in-advance constraint) implies that interest rate changes have no effect on labor supply (Christiano and Eichenbaum 1992; Ravenna and Walsh, 2006).

$$\int_0^1 P_t(i)C_{h,t}(i)di \leq W_t L_{h,t} + M_{h,t} - D_{h,t} \tag{4}$$

Household's problem can be solved in two steps: first, for a given amount of aggregate consumption it minimizes the expenditure determining the demand for each good. The demand for each type of good can be then determined solving the following problem:

$$\begin{aligned} &min \int_0^1 P_{h,t}(i)C_{h,t}(i)di \\ &s.t\ C_{h,t} = \left[\int_0^1 C_{h,t}(i)^{\frac{\varepsilon}{\varepsilon-1}} di\right]^{\frac{\varepsilon-1}{\varepsilon}} \end{aligned} \tag{5}$$

Minimizing with respect to $C_{h,t}(i)$ yields:

$$C_{h,t}^*(i) = \left[\frac{P_t(i)}{P_t}\right]^{-\varepsilon} C_{h,t} \tag{6}$$

where the aggregate price index P_t is defined as[3]

$$P_t = \left[\int_0^1 P_t(i)^{1-\varepsilon}\, di\right]^{\frac{1}{1-\varepsilon}} \tag{7}$$

Integrating (6) across households yields total demand of variety i as follows:

$$C_t^*(i) = \left[\frac{P_t(i)}{P_t}\right]^{-\varepsilon} C_t \tag{8}$$

Using the aggregate price index P_t and the optimal demand for each type of good, the optimum minimized expenditure is given by:

$$\int_0^1 P_t(i)\, C_{h,t}^*(i) di = P_t C_{h,t} \tag{9}$$

Second, given the optimal allocation of consumption expenditure across differentiated goods, households must choose optimal state-contingent paths of total amount of consumption and savings (money), and the optimal amount of the quantity of labor supplied. To this end, they maximize their lifetime utility (1) subject to a sequence of budget constraints (3), (9), and (4). Optimizing behavior further implies that the budget constraint holds with equality in each period. The necessary and sufficient conditions are standard. Optimal allocation of households' consumption over time implies the standard Euler equation:

$$\beta R_t E_t \left[\frac{(C_t)^{-\sigma} P_t}{(C_{t+1})^{-\sigma} P_{t+1}}\right] = 1 \tag{10}$$

Note that index h is dropped because of symmetry. The relevant necessary and sufficient condition for hours worked is given by:

$$\frac{W_t}{P_t} = L_t^{\varphi} C_t^{\sigma} \tag{11}$$

2.2 Productive sector

The productive sector of our economy consists of two sub-sectors: a manufacturing sector made of perfectly competitive firms producing a homogenous intermediate good and a retail sector that operates under monopolistically competition to sell the final good to households. The introduction of retailers is useful in introducing nominal rigidities.

2.2.1 Manufacturing firms

A mass one continuum of perfectly competitive manufacturing firms, indexed by $j \in [0,1]$, produces a homogenous intermediate good $I_{j,t}$ using labor $L_{j,t}$, which it sells to retail firms at price $Q_{j,t}$.

[3] The price index has the property that the minimum cost of a consumption bundle C_t is $P_t C_t$.

$$I_{j,t} = L_{j,t} \tag{12}$$

Following Ravenna and Walsh (2006), we assume that the typical manufacturing firm has to pay labor costs before sales revenues are realized (working capital hypothesis). Furthermore, we maintain that the *j*-th manufacturing firm finances this working capital requirement (labor costs) by using a composite constant elasticity of substitution basket of imperfectly substitutable heterogeneous loans – each supplied by a branch of a bank x – with a time-invariant elasticity of substitution among varieties of loans ε^b, namely:

$$B_t(j) = \left[\int_0^1 B_t\,(j,x)^{\frac{\varepsilon^b-1}{\varepsilon^b}} dx\right]^{\frac{\varepsilon^b}{\varepsilon^b-1}} \tag{13}$$

In other words, each manufacturing firm borrows an amount $B_t(j)$ made of a continuum of loans, $B_t(j,x)$ from *all* existing banks $\forall\, x \in [0,1]$. The introduction of a Dixit-Stiglitz framework allows us to model market power in the financial intermediary sector (loan branch) and derive loan rate setting as a bank's optimal decision (see Benes and Lees, 2007; Gerali et al. 2010). To keep the model simple, we also assume that these loans are obtained at the beginning of the period and repaid in full at the end of the same period as in Ravenna and Walsh (2006).

The *j*-th firm's demand for loans issued by the *x*-th financial intermediary $B_t(j,x)$ is given by minimizing total borrowing costs subject to the Dixit-Stiglitz composite aggregating the differentiated loan variety x:

$$min \int_0^1 R_t^L(x) B_t(j,x) dx$$

$$s.t\;\; B_t(j) = \left[\int_0^1 B_t\,(j,x)^{\frac{\varepsilon^b-1}{\varepsilon^b}} dx\right]^{\frac{\varepsilon^b}{\varepsilon^b-1}}$$

Minimizing with respect to $B_t(j,x)$ yields downward-sloping demand curves facing the x-th bank, i.e. banks exploit any relative loan rates differences in creating their loan basket:

$$B_t(j,x) = \left(\frac{R_t^L(x)}{R_t^L}\right)^{-\varepsilon^b} B_t(j) \tag{14}$$

The aggregate loan rate index R_t^L is defined by the following equation:

$$R_t^L \equiv \left[\int_0^1 (R_t^L(x))^{1-\varepsilon^b} dx\right]^{1/(1-\varepsilon^b)} \tag{15}$$

where $R_t^L(x)$ is the gross interest rate contracted with the x-th bank. Equation (14) denotes that the optimal demand for loans issued by the x–th bank is a *relative* demand; it depends on the relative loan rate charged by the x–th bank.

In a second stage, the typical manufacturing firm's decision problem is to choose the level of employment $H_{j,t}$ and the loans composite $B_t(j)$, to maximize the expected present discounted value of its lifetime profits (equation (16)):

$$E_0 \sum_{t=0}^{\infty} \Lambda_{0,t} \left[Q_{j,t} L_{j,t} + P_t B_t(j) - (1-\tau) W_t L_{j,t} - \int_0^1 R_t^L(x) P_t B_t(j,x) dx \right] \tag{16}$$

where $\Lambda_{0,t} \equiv \beta(U_{C,t}/U_{C,0})(P_t/P_0)$ denotes the representative household's stochastic discount factor. The j-th firm's cash flow in period t equals sales revenues $Q_{j,t}L_{j,t}$ plus what the firm obtains from borrowing $B_t(j)$, minus labor and borrowing costs $(1-\tau)W_t L_{j,t} + \int_0^1 R_t^L(x) B_t(j,x) dx$. To eliminate all distortions in the steady-state equilibrium the fiscal authority subsidizes labor costs at a rate τ.

Using the aggregate loan rate index R_t^L and the optimal demand for each type of loan $B_t(j,x)$, i.e. equations (14) and (15), the optimum minimized borrowing costs are given by:

$$\int_0^1 R_t^L(x) B_t(j,x) dx = R_t^L(x) B_t(j)$$

The optimization problem is subject to the Dixit-Stiglitz aggregator (equation (13)) and to the working capital requirement (equation (17)). According to the latter the amount of differentiated loans that the *j*-th manufacturing firm borrows from a representative bank (to pay households wages at the beginning of the period, i.e. before production and sales take place) should be at least equal to labor costs:

$$P_t B_t(j) \geq (1-\tau) W_t L_{j,t} \tag{17}$$

Maximizing with respect to $L_{j,t}$ yields:

$$Q_{j,t} (= Q_t) = (1-\tau) W_t R_t^L \tag{18}$$

Equation (18) is the optimal pricing of the intermediate goods sold by the *j*-th manufacturing firm. This price reflects typical manufacturing firm's borrowing costs as a result of the working capital requirement.

2.2.2 Retail firms

We assume a continuum of monopolistically competitive retail firms indexed by i on the interval $[0,1]$. Retailers buy intermediation goods at price $Q_{j,t} (= Q_t)$ and transform them into differentiated final consumption goods for the households. The typical i–th retail firm produces output $Y_{i,t}$ according to the following constant return to scale technology, and sells it at a price $P_{i,t}$.

$$Y_{i,t} = I_{i,t}^d \tag{19}$$

where $I_{i,t}^d$ denotes the demand for intermediate goods by the *i*-th retail firm. Equation (19) implies a constant rate of transformation in a "1-1" analogy. Similarly, assuming an analogy "1-1" between the *i*-th retail firm and the *j*-th manufacturing firm we get that $I_{i,t} = I_{j,t}$. The nominal marginal cost of each retail firm is $MC_t \; (= MC_{i,t}) \equiv Q_t$. Therefore, using equation (18), the marginal cost is equal to:

$$MC_t = (1-\tau) W_t R_t^L \tag{20}$$

Following the bulk of the literature, we assume that prices are set in staggered contracts with random duration as in Calvo (1983): in any period each firm faces a constant probability $1-\theta$ to re-optimize and charge a new price, independently of the time elapsed since the last adjustment. Thus, θ is a natural index of price stickiness. A retail firm re-optimizing in period t will choose the price $P_{i,t}^{*}$ that maximizes its intertemporal profits generated (equation (21)) while that price remains effective subject to the demand derived from households' maximization (equation (22) in conjuction with equation (7)):

$$max\{P_{i,t}^{*}\}E_0\sum_{t=0}^{\infty}\theta^t \Lambda_{0,t}\left[\left(P_{i,t}^{*}-MC_t\right)Y_{i,t}\right] \tag{21}$$

$$s.t.\;\; Y_{i,t}=\left(\frac{P_{i,t}}{P_t}\right)^{-\varepsilon}Y_t \tag{22}$$

where P_t is the aggregate price index (equation (7)) , Y_t is aggregate demand, and $\varepsilon>1$ represents the (constant) elasticity of substitution across differentiated final goods[4]. The resulting first-order condition is standard and defines the optimal price setting rule for the i-th retail firm as follows:

$$\frac{P_{i,t}^{*}}{P_t}=\frac{\varepsilon}{\varepsilon-1}\frac{E_t\sum_{k=0}^{\infty}\theta^k\beta^k\left(U_{C,t+k}/U_{C,t}\right)\left(MC_{t+k}/P_{t+k}\right)\left(P_{t+k}/P_t\right)^{\varepsilon}Y_{t+k}}{E_t\sum_{k=0}^{\infty}\theta^k\beta^k\left(U_{C,t+k}/U_{C,t}\right)\left(P_{t+k}/P_t\right)^{\varepsilon-1}Y_{t+k}} \tag{23}$$

In the symmetric equilibrium, the aggregate price dynamics are determined by the following price aggregate P_t :

$$P_t=\left[(1-\theta)(P_t^{*})^{1-\varepsilon}+\theta\left(P_{t-1}\right)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}} \tag{24}$$

The price level P_t is determined in each period as a weighted average of a fraction of firms $1-\theta$ that resets their prices and a fraction of firms θ that leaves their prices unchanged.

2.3 The banking sector

The banking sector in our model is split into two parts: a loan branch and a deposit branch. The deposit market is perfectly competitive and thus the deposit rate is equal to the policy rate, $R_t^D=R_t$. This assumption permits us to focus our attention on the effects of bank capital requirements on the loan market. By contrast, the loan market is modeled along Gerali et al. (2010), with a Dixit-Stiglitz type of competition. We abstract from loan rate stickiness and strategic interactions between banks. In our setting, each bank takes the market-wide developments as given since it has zero impact on sector-wide aggregates.[5]

There is a continuum of representative banks indexed by x where $x\epsilon(0,1)$. The $x-$ th bank raises funds through deposits $D_t(x)$ and bank capital $K_t^b(x)$ in order to supply loans to a $B_t(x)$ continuum of manufacturing firms. The balance-sheet constraint is given by:

$$B_t(x)=D_t(x)+K_t^b(x) \tag{25}$$

Following Gerali et al. (2010), bank capital is accumulated out of retained profits:

[4] Given that firms are owned by households, the appropriate discount factor for firms is based on the representative household's discounted marginal utility of future consumption relative to the marginal utility of current consumption.
[5] For the alternative approach, see Cuciniello and Signoretti (2014) and Chrysanthopoulou (2021).

$$K_t^b(x) = (1-\delta)\, K_{t-1}^b(x) + V_t^b(x) \tag{26}$$

where δ is a fraction of bank capital that is consumed in each period (depreciation rate) and $V_t^b(x)$ denotes bank's profits. As in Gerali et al. (2010), the representative bank has an exogenous target leverage ratio v and pays a cost (parameterized by k_{Kb}) whenever the capital-to-loan ratio $K_t^b(x)/B_t(x)$ (the inverse of a leverage ratio) deviates from that target.[6] Namely, we assume the following quadratic function:

$$\frac{\kappa_{Kb}}{2}\left(\frac{K_t^b(x)}{B_t(x)} - v\right)^2 K_t^b(x) \tag{27}$$

which represents the cost from deviating from the target capital to assets ratio. The existence of this target is a simple shortcut for studying the implications and costs of regulatory capital requirements. It allows the incorporation of bank's concerns for its balance sheet conditions (and the concomitant loan rate settlements and credit expansion) into the model.

The x −th bank chooses the nominal loan rate $R_t^L(x)$ to maximize the following profit function:

$$V_t^B(x) = R_t^L(x)B_t(x) - R_t D_t(x) - \frac{\kappa_{Kb}}{2}\left(\frac{K_t^b(x)}{B_t(x)} - v\right)^2 K_t^b(x) \tag{28}$$

The maximization takes place subject to the loan demand (equation (14)), for $\forall j\epsilon x$ and the balance-sheet constraint (equation (25)). In a symmetric equilibrium, i.e. $R_t^L(x) = R_t^L$, the solution to the bank's problem is given by:

$$R_t^L = \frac{\varepsilon^b}{\varepsilon^b - 1} R_t \; - \frac{\varepsilon^b}{\varepsilon^b - 1} k_{kb}\left(\frac{K_t^b}{B_t} - v\right)\left(\frac{K_t^b}{B_t}\right)^2 \tag{29}$$

Equation (29) can be interpreted as a loan supply schedule; when loans increase, the capital-asset ratio falls below target, inducing the typical bank to raise the loan rate. In other words, credit supply to the real economy is constrained by the availability of bank capital (as in the Basel II regulation). Since, bank capital can *only* be accumulated through retained earnings, macroprudential policy gains significance, and a feedback loop (financial accelerator) emerges from the supply side of the credit market.

2.4 Macroeconomic authorities

2.4.1 Monetary authority

We consider instrument rules in the sense of a feedback rule for the instrument (short-term nominal interest rate R_t) as a function of macro variables. Thus, the policy rate is set in response solely to current inflation (strict inflation targeting) or in response to both current inflation and output gap (flexible inflation targeting).[7]

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[6] The target can be interpreted as an exogenously given constraint stemming, for example, from prudential regulation.

[7] For expositional reasons (facilitate straightforward identification of the cost channel effects), the interest rate rule abstains from elements found to be empirically relevant such as forward-looking elements and interest rate smoothing (see, e.g. Clarida et al. 2000).

$$R_t = R\left(\frac{\Pi_t}{\Pi}\right)^{\varphi\Pi} \tag{30}$$

$$R_t = R\left(\frac{\Pi_t}{\Pi}\right)^{\varphi\Pi}\left(\frac{Y_t}{Y}\right)^{\varphi Y} \tag{31}$$

where Π_t is the gross inflation rate, defined as $\Pi_t \equiv P_t/P_{t-1}$. Parameters $\varphi_\Pi, \varphi_Y > 0$ indicate the aggressiveness of the central bank in stabilizing inflation and the output gap respectively.

2.4.2 Government

The government uses an employment subsidy τ in order to ensure the efficient steady state. Lump-sum taxation T is used to finance this subsidy. We shall then assume that lump-sum taxation cannot be used to alter this subsidy.

$$P_t T = \tau W_t L_{j,t} \tag{32}$$

2.4.3 Macroprudential authority

In what follows we have two choices. First, to assume that the macroprudential authority imposes an exogenous (time-invariant) capital requirement (target) v to banks. In this case, we account for Basel II-type bank capital regulations. Second, to assume that capital-assets ratio to be one of the macroprudential policy instruments and thus time-variant, i.e. V_t (see equation (33)). This permits us to study countercyclical capital buffers, as proposed by Basel III. Following Angelini et al. (2012, 2014), Brzoza-Brzezina et al. (2013), and Hollander (2017), we assume that the macroprudential authority, besides v in equation (27), it also sets a *time-varying* capital requirement according to the rule: [8,9]

$$V_t = V\left(\frac{Y_t}{Y}\right)^{\chi V} \tag{33}$$

where χ_V amounts to a countercyclical policy: capital requirements increase in good times (banks must hold more capital for a given amount of loans) and decrease in recessions. We set $\chi_V = 0.5$ (Angelini et al. 2012 and 2014; Brzoza-Brzezina et al. 2013; and Hollander 2017).

2.5 Aggregation and equilibrium

Market clearing in the goods market implies that $Y_{i,t} = C_{i,t}$. Defining $Y_t \equiv \left[\int_0^1 Y_{i,t}^{\frac{\varepsilon-1}{\varepsilon}} di\right]^{\frac{\varepsilon}{\varepsilon-1}}$ and using equation (8), the aggregate goods market condition becomes:

$$Y_t = C_t \tag{34}$$

Combining equations (34), (8), (19) yields $I_{i,t}^d = \left(\frac{P_{i,t}}{P_t}\right)^{-\varepsilon} Y_t$. Integrating across retail firms, using then (i) $\int_0^1 I_{i,t}^d di = I_t$ (market clearing equation for the retail goods sector), (ii) equation (12) in a symmetric

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[8] Our notion of macroprudential policy relates only to its countercyclical properties and disregards the "financial sector risk-preventing" approach of many policymakers. Our results should be interpreted in light of the above.

[9] In this rule we abstain from v_{t-1}, i.e. the idea that policymakers alter required capital very smoothly, to keep the analysis simple.

equilibrium, and (iii) market clearing condition in the labor market ($\tilde{L}_t = L_t,$ where $\tilde{L}_t = \int_0^1 \tilde{L}_{j,t}\, dj$), we obtain the following aggregate production function:

$$Y_t \Delta_t = L_t \tag{35}$$

where Δ_t is defined as the price dispersion index , $\Delta_t \equiv \int_0^1 \left(P_{i,t}/P_t\right)^{-\varepsilon} di.$

The aggregate demand of the model can be derived after imposing equation (34) to equation (10):

$$\beta R_t E_t \left[\frac{\left(Y_t\ \right)^{-\sigma} P_t}{\left(Y_{t+1}\right)^{-\sigma} P_{t+1}} \right] = 1 \tag{36}$$

The aggregate supply is described by the following standard equation:

$$\frac{1-\theta \Pi_t^{\varepsilon-1}}{1-\theta} = \left[\frac{E_t \sum_{f=0}^{\infty} (\theta\beta)^f MC_{t+f} \Pi_{t,t+f}^{\varepsilon}}{E_t \sum_{f=0}^{\infty} (\theta\beta)^f \Pi_{t,t+f}^{\varepsilon-1}} \right]^{1-\varepsilon} \tag{37}$$

Equation (37) relates aggregate output supply to inflation, conditional on expectations about future variables.

2.6. The flexible-price equilibrium

When prices are flexible, real marginal cost $MC_t^{r,f}$ is equal to the inverse of the constant mark-up:

$$MC_t^{r,f} = (1-\tau) W_t^{r,f} R_t^{L,f} = \frac{\varepsilon - 1}{\varepsilon} \tag{38}$$

Using equations (38), (11), (34), and (35) yields:

$$\frac{W_t}{P_t} = L_t^{\varphi} C_t^{\sigma} = \frac{\varepsilon - 1}{\varepsilon} \frac{1}{R_t^{L,f}(1-\tau)}$$

Therefore,

$$Y_t^{\varphi+\sigma} = \frac{\varepsilon - 1}{\varepsilon} \frac{1}{R_t^{L,f}(1-\tau)}$$

2.7 Steady state

We focus on a zero inflation non-stochastic efficient steady-state equilibrium. It is straightforward to prove that the steady state level of the gross inflation rate and price dispersion are equal to one, ($\Pi = 1$) and ($\Delta = 1$), using the aggregate demand and the law of motion for price dispersion. From the households' Euler equation (10), we obtain the steady-state gross interest rate $\beta = r^{-1}$. The government is responsible for offsetting the static distortions arising from the imperfect substitutability of intermediate goods and loan types. The working capital needs call for for financial intermediation which takes place under monopolistic competition. A subsidy τ is used to equate the marginal rate of substitution between consumption and labor $MRS_{L,C}$ to the marginal productivity of labor MP_L $(=1)$. This implies setting τ to ensure $MRS_{L,C}(=L^{\varphi}C^{\sigma})=W/P=MP_L$ $(=1)$. Therefore, $L^{\varphi}=C^{-\sigma}$. The goods market clearing condition (equation (34)), together with the production function (equation (35)), imply the Pareto efficient values of output and employment, $Y=L=1$.

Note also that we depart from the model proposed by Gerali et al. (2010) in the sense that our approach allows for banks to diverge from prescribed regulatory capital ratio targets. This feature introduces a more realistic portrayal of how banks operate in practice. Empirical evidence (e.g. Meh and Moran 2010; De Walque et al. 2010) suggests that banks tend to hold capital buffers well above the regulatory requirements. Excess capital buffers can, in turn, influence banks' lending behavior and economic aggregates. Thus, we assume that in steady state $K^b/B\neq v$ as in Benes and Kumhof (2015) and Hollander (2017).

2.8 Aggregate dynamics

Log-linearizing the model around the non-stochastic steady state allows to fully characterize the equilibrium dynamics at a first-order accuracy. All lower-case variables denote log deviations from the steady-state: $x_t=\ln(X_t)-\ln X$, where X is the steady state value of x_t. Log-linearization of the aggregate demand equation yields:

$$y_t=E_t y_{t+1}+\sigma^{-1}(r_t-E_t\pi_{t+1}) \quad (39)$$

Equation (39) is the forward-looking IS curve that relates the output gap to the expected rate of output growth and the real interest rate.

Using equation (37), the evolution of the inflation is described by the linearized New-Keynesian Phillips curve with $k\equiv(1-\theta)(1-\theta\beta)/\theta$.

$$\pi_t=\beta E_t\pi_{t+1}+kmc_t$$

Equations (20), (11), (35), and (34) jointly imply that:

$$mc_t=(\sigma+\varphi)y_t+r_t^L$$

Combining the last two equations yields the short-run New-Keynesian Phillips curve (NKPC):

$$\pi_t=\beta E_t\pi_{t+1}+k(\sigma+\varphi)y_t+kr_t^L \quad (40)$$

The NKPC relates inflation to the expected future inflation, the output gap, and the loan rate set by imperfect competitive banks. As in the canonical model without the cost channel, the term $k(\sigma+\varphi)$ captures the sensitivity of inflation to movements in the output gap. Comparing our Phillips curve (equation (40)), with the corresponding equation in the baseline Ravenna-Walsh model (equation (41)), where firms borrow at the policy rate, since the banking sector is perfectly competitive, yields valuable insights.

$$\pi_t=\beta E_t\pi_{t+1}+k(\sigma+\varphi)y_t+kr_t \quad (41)$$

Specifically, it is evident that embedding the cost channel of monetary policy with bank capital requirements results in a *modified* New-Keynesian Phillips curve, since $r_t^L\neq r_t$.

The log-linearized version of the optimal loan rate setting, equation (29), becomes:

$$r_t^L = Fr_t + \Xi lev_t \tag{42}$$

where $lev_t \equiv b_t - k_t^b$ is the bank leverage. Notice that two crucial composite parameters emerge from introducing bank capital holdings deviations from targets:

$$F \equiv \left[1 - \frac{k_{kb}}{r}\left(\frac{K^b}{B} - v\right)\left(\frac{K^b}{B}\right)^2\right]^{-1},$$

and

$$\Xi \equiv \left[r\left(1 - \frac{k_{kb}}{r}\left(\frac{K^b}{B} - v\right)\left(\frac{K^b}{B}\right)^2\right)\right]^{-1}\left(\frac{K^b}{B}\right)^2\left(\frac{3K^b}{B} - 2v\right)k_{kb}$$

We distinguish two cases. First, assuming that $K^b/B = v$ yields $\Xi \equiv k_{kb}v^3/r$ and $F = 1$ as per Gerali et al. (2010). Second, our setting allows banks to deviate from regulatory capital assets ratio, that is, $K^b/B \neq v$. In this case, note that F is larger than one (Figure 1). Hence, the effects of a change in the monetary policy rate r_t on the loan rate r_t^L are amplified when holdings of bank capital K^b/B are well above the required levels, thereby leading to a more complete interest rate pass-through. Furthermore, when banks voluntarily keep higher than required capital ratios, they experience higher market confidence in their financial strength and stability which translates into lower funding costs and a better ability to pass on policy rate changes to borrowers. Thereby, excess bank capital holdings generate heterogeneity in the interest rate pass-through. Ultimately, these differences via the cost channel of monetary policy can influence inflation as evidenced in equation (41). Figure 1 presents the heterogeneity in the interest rate pass-through (left panel) and in the bank leverage impact on labor supply (right panel) generated by our setting for $K^b/B \in (0.14,\ 0.24,\ 0.33)$. These values are in line with capital adequacy ratios as per Meh-Moran (2010), de Walque et al. (2010) and Hollander (2017). Evidently, the increase in the capital-loan ratio significantly increases the cost of credit and restricts credit supply.

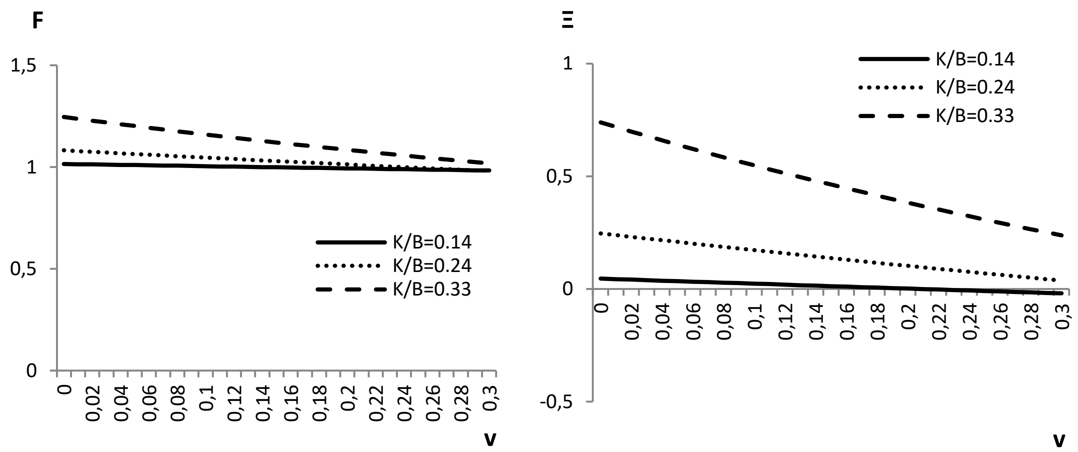

Figure 1. Bank Capital Holdings Deviations from Targets. Left Panel: Heterogeneity in the interest rate pass-through; Right Panel: Heterogeneity in the bank leverage impact on labor supply.

The left panel of Figure 1 also shows that stricter prudential regulations, reflected in higher values of v, lower F closer to the value of one (for benchmark parameter values outlined in Section 3). Finally, higher values of v are likely to impose constraints on the relationship between bank leverage lev_t and loan rate r_t^L described in equation (42). That is, $d\Xi/dv < 0$ when $K^b/B \neq v$.

Two points are worthy of consideration. First, the combination of equation (40) with equation (42) indicates that the cost channel assigns macroprudential regulations (regulatory capital requirements) and bank capital holdings deviations a pivotal role in determining inflation and, consequently in generating possible indeterminacy. Second, regulatory capital requirements imply that bank capital may act as an amplification mechanism of the real impacts of aggregate shocks. In particular, equation (43) shows the positive relationship between bank leverage and output under both strict ($\varphi_Y = 0$) and flexible ($\varphi_Y \neq 0$) inflation targeting regimes:[10]

$$lev_t = X\{[(r + spr(1-\delta))(1+\sigma+\varphi) - \delta v \varphi_Y]y_t - \delta v \varphi_\Pi \pi_t - (rv + spr)(1-\delta)k^b_{t-1}\} \quad (43)$$

where $X \equiv \frac{(1-v)}{(rv+spr+\delta k_{kb} v^3)(1-v)-\delta rv}$

Based on our (standard) parameter values, $dlev_t/dy_t > 0$, thus indicating a procyclical bank leverage. In other words, increases in economic activity are associated with increases in leverage (Adrian and Shin 2014). In particular, output affects bank leverage through two channels. First, output shifts lead to higher deposits. As a consequence, the fall in profits results in lower bank capital and thus higher bank leverage. Second, an increase in output leads to positive changes in loan demand and, thereby, in bank leverage. Yet, the increase in loan demand raises bank profits and capital[11] and decreases bank leverage. The former effect dominates rendering the relationship between y_t and lev_t positive.

The log-linearized version of the monetary and macroprudential policy rules are given below:

$$r_t = \varphi_\Pi \pi_t \quad (44)$$

$$r_t = \varphi_\Pi \pi_t + \varphi_Y y_t \quad (45)$$

$$v_t = \chi_V y_t \quad (46)$$

An interesting issue is whether countercyclical bank capital regulations promote equilibrium determinacy. To answer this question, note first that the first-order condition for banks (equation (42)), when bank capital requirements depend on the state of the economy (equation (46)), reads as follows:

$$r^L_t = Fr_t + \Xi lev_t + \Xi v_t \quad (47)$$

3 Equilibrium Determinacy

In the present section, we investigate the REE properties of our model using Woodford's (2003) methodology. Our setting allows us to clearly disentangle and intuitively demonstrate the different mechanisms linking the credit market conditions to the macroeconomy and explain the implications for the local determinacy of the REE.

We further evaluate the empirical plausibility of our results through a numerical simulation of the model. To illustrate our findings, we use benchmark parameter values. In particular, we set $\beta = 0.99$, which implies an annualized nominal bond rate equal to 4%. We also set the elasticity of hours worked, $\varphi = 0$, following much of the macro-literature (Hansen 1985; Rogerson 1988; Ireland 2004; Smith 2016), and $\sigma = 1$. In line with Gerali et al. (2010), we impose $k_{kb} = 11$. We also set $\theta = 0.75$ as suggested by Dhyne et al. (2006) and $\delta = 1$ for expositional reasons. Finally, we consider two alternative values for bank capital holdings: $K^b/B = 0.14$ (baseline value) as per Meh-Moran (2010) and $K^b/B = 0.33$ as in Hollander (2017).

3.1 Strict inflation targeting and Basel-type capital regulations regimes

[10] For the derivation of equation (43) see Appendix 1.
[11] Empirical evidence suggests that the overall bank profits are procyclical (Albertazzi and Gambacorta 2009).

We start by exploring the conditions for the existence of a unique REE when the central bank has an exclusive concern for price stability and time-invariant capital regulations are at work (Section 3.1.1). Then, we consider the extent to which those conditions are modified (if so) with countercyclical capital buffers (Section 3.1.2).

3.1.1 Strict inflation targeting and Basel-II type capital regulations (Benchmark case)

*Proposition 1***.** *When the monetary authority is primarily or exclusively concerned with inflation stability and the cost channel is driven by Basel-II type bank capital regulations, there exists a unique REE path converging to the steady state of the economy if:*

i) $1 < \varphi_{\Pi} < \varphi_2 \equiv \frac{\sigma(1-\beta)}{k[-\sigma-\varphi-\Xi(1+\varphi+\sigma-K_2+\sigma K_3)+\sigma F]}$, for $v < v_1$ (48)

ii) $1 < \varphi_{\Pi} < \varphi_1 \equiv \frac{2\sigma(1+\beta)+k[\sigma+\varphi+\Xi(1+\varphi+\sigma)]-k\Xi K_2}{k[2\sigma F-\sigma-\varphi-\Xi(1+\varphi+\sigma-K_2+2\sigma K_3)]}$, for $v > v_1$ (49)

where $K_2 \equiv X[(r + spr + k_{kb}v^3)(1-v) - r]\delta(1+\varphi+\sigma)(1-v)$ and $K_3 \equiv X\delta v$.

Proof. See Appendix 2.

Comparing conditions (48) and (49) with those that emerge for $v = 0$ ($\Xi = 0$, standard cost channel model) yields useful insights. First, the width of the determinacy region depends now on the level of strictness of the prudential regulations v as well as on bank capital holdings K^b/B. Second, for $v < v_1 = 0.09$, we determine an extra upper constraint, namely φ_2. Even though our simple-minded bank capital ratio target does not have a literal counterpart that would allow us to determine v with precision, these values fall within the range of empirical plausibility (see, for example, World Bank 2019). Moreover, it is more likely that φ_2 is binding as the weight of the cost channel is relatively larger than the weight of the novel bank-leverage channel (see below) and the demand channel of monetary policy transmission, thus generating an upper bound on the inflation coefficient.

In Figure 2 we plot the regions of (in)determinacy in the parameter space (φ_{Π}, v) for three alternative cases: i) $K^b/B = v$ (panel a) ii) $K^b/B = 0.14$ (our baseline case) (panel b), and $K^b/B = 0.33$ (panel c). Most interestingly, the upper constraint φ_2 dramatically restricts the determinacy region relative to the standard case of the cost channel with no capital requirements. Indeed, ruling out regulatory capital requirements ($v = 0$) determinacy is attained when the central bank satisfies the Taylor principle with a quite relaxed upper bound to inflation responses. That is, $1 < \varphi_{\Pi} < 47.39$.

However, the upper bound becomes a serious concern in the presence of Basel II-type bank capital regulations and excess bank capital holdings. For instance, for $v = 0.06$ the upper bound is 47.37 for $K^b/B = v$ (i.e. almost the same as with the standard case with no capital requirements), whereas it considerably reduces to 16.2 for $K^b/B = 0.14$. The determinacy regions shrink drastically in the case of excessively capitalized banking system; for $v = 0.08$ and $K^b/B = 0.33$ the upper bound drops to a mere 1.98. The basic intuition goes as follows. When banks hold significantly more capital than required by regulation, the interest rate pass-through is more pronounced (F is higher)[12] and the elasticity of loan rates to bank leverage (Ξ) is higher. Therefore, the cost channel of monetary policy is stronger leading to shrinking regions of REE determinacy.

[12] Banks with stronger capital positions are more willing and capable of adjusting their lending rates in response to changes in central bank policy rates because they have a more stable financial base, improved access to funding, better compliance with regulations, and greater flexibility in managing risks.

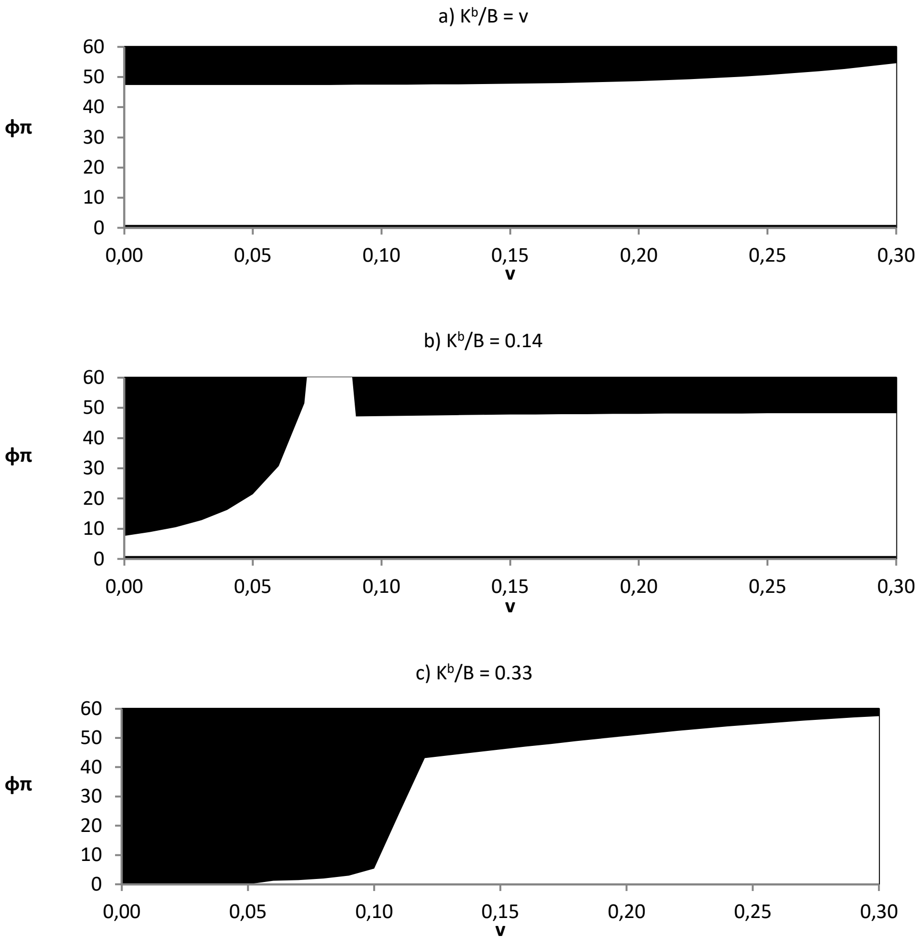

Figure 2. Determinacy, strict inflation targeting, and Basel-II type capital regulations.
Note: Simulations are based on baseline parameter values. Determinacy (white area). Indeterminacy (dark area).

Proposition 2. Capital requirement stringency increases the upper bound on the inflation parameter and shrinks the indeterminacy area.

Proposition 3. Excess bank capital holdings decrease the upper bound on the inflation parameter and expand the indeterminacy area.

Proof. Differentiating the upper bounds φ_1 and φ_2 with respect to v and K^b/B we obtain respectively:

$$\frac{\partial \varphi_1}{\partial v} > 0 \text{ and } \frac{\partial \varphi_2}{\partial v} > 0 \tag{50}$$

$$\frac{\partial \varphi_1}{\partial (K^b/B)} < 0 \text{ and } \frac{\partial \varphi_2}{\partial (K^b/B)} < 0 \tag{51}$$

In Figure 2 the upper bound increases sharply with higher time-invariant capital requirements. If regulators discourage high levels of leverage, active monetary policy should be less aggressive to guarantee that REE is unique.[13] The reason is that when the cost channel is switched on, strict Basel-II type bank capital regulations affect banks' balance sheets (the supply side of the credit market), lending conditions, and in the presence of the cost channel, inflation. In the case of over-capitalised banks, higher values of F and Ξ result on a more pronounced cost channel of monetary policy, restricting the determinacy area (decreasing the upper bound).

[13] The opposite effect holds (reduction of the determinacy region) for higher values of k_{kb}.

Proposition 4. REE determinacy is never attained, when banks' capital holdings deviate significantly from regulatory targets and the central bank acts as a pure inflation targeter.

Proof. See Appendix 3.

This result challenges the common result of the literature regarding the cost channel of monetary policy transmission, namely that strict inflation targeting ensures determinacy (Brückner and Schabert 2003; Surico 2008; Aksoy and Basso 2011). In our setting, for large enough values of bank capital holdings, *i*.e. when $K^b/B > 0.28$, equilibrium multiplicity becomes a reason of concern for the non-accommodating central bank. The intuition for instability is straightforward. There are three transmission channels of the policy rate to inflation; the demand channel, the cost channel, and the bank's leverage channel. The latter (novel) channel emerges from the assumption of loan supply dependence on the bank's leverage. Particularly, following a belief-driven surge in inflation, a policy rate hike reduces output and inflation. This is the demand which leads to lower real wages and bank leverage (as shown in equation (43)) and results in reduced loan rates. Here, the bank's leverage effect reinforces the demand channel. For excessive bank capital holdings, e.g. when $K^b/B = 0.33,$ the stronger cost channel (due to higher values of Ξ and F) outweighs both the demand and the bank's leverage channel; the possibility of self-fulfilling inflation expectations is present for $v < v_2 = 0.06$ (Figure 2, panel c).[14]

We further explore whether our previous key results are robust to i) different calibration values of the model's deep parameters, and ii) the forward-looking version of the feedback interest rule, equation (44). Until now, our benchmark parameterization expresses a situation in which the weight of the cost channel of monetary policy transmission is relatively larger than the weight of the demand channel, i.e. we assume that $\varphi < \sigma$. Indeed, for a given intertemporal elasticity of substitution $(1/\sigma)$, an increase in the real rate boosts labor supply and reduces real wage, and thus marginal cost and inflation. The lower the φ (i.e. the higher the labor supply elasticity), the smaller the decline in real wages for a given change in the nominal interest rate[15,16]. In addition, higher values of θ imply that real movements put small upward pressure on inflation. In this case, the Phillips curve becomes flatter and the demand channel is restricted.

For robustness check, we consider an alternative parameterization that increases the relative importance of the traditional demand channel (lower values of θ and higher than σ values of φ). We find that our results survive with lower values of the Calvo stickiness parameter, i.e. when $\theta = 0.6$ as suggested by Bils and Klenow (2004). In the case of $\varphi > \sigma,$ there is no upper bound on the inflation coefficient for all values of v. This finding is in line with the findings of Surico (2008) and Llosa and Tuesta (2009). In addition, our findings regarding the critical values of v in terms of dynamic stability, e.g. v_1 and v_2, are not qualitatively affected and quantitatively differentiated by higher values of σ. For instance, for $\sigma = 2$, the main result carries over: the same moderate level of v, that is, $v > v_1 = 0.09$, shrinks the determinacy region, while for $K^b/B = 0.33$ and $v < v_2 = 0.07$ time-invariant capital regulations result in multiple equilibria. Furthermore, in line with Llosa and Tuesta (2009), the inclusion of interest rate rules with forward expectations, i.e. $r_t = \varphi_\Pi E_t \pi_{t+1}$, induces indeterminacy. Indeed, it can be shown that v becomes irrelevant for determinacy and that determinacy is not attainable as the upper bound is below the lower bound, that is $(1-\beta)/k < 1$.[17]

In sum, a stringent time-invariant capital regulatory regime (in the form of Basel II) reduces the possibility of determinacy problems. Furthermore, by reinforcing the demand channel, procyclical bank leverage minimizes the possibility of self-fulfilling business cycles under strict inflation targeting. However, this is true as long as banks do not hold capital ratios well above the required ones. These are novel findings given that previous studies disregard the role of monetary and macroprudential policy interactions and bank capital holdings in equilibrium determinacy (Brückner and Schabert 2003; Surico 2008; Llosa and Tuesta 2009) or focus on the amplifying effect of capital regulations on fundamental shocks (Covas and Fujita 2010; Angelini et al. 2010; Repullo and Suarez 2013; Angeloni and Faia 2013).

3.1.2 Strict inflation targeting and Basel-III type capital regulations

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[14] For $K^b/B = 0.33$ and $0.12 < v < 0.06$ the determinacy region is drastically restricted (extreme low values for φ_2).

[15] For a similar reasoning see Surico (2008) and Llosa and Tuesta (2009).

[16] In this case, an upper bound may be imposed to the interest rate response to current inflation that guarantees a unique equilibrium.

[17] All proofs for robustness checks are available from the authors upon request.

We now consider the determinacy implications for strict inflation targeting regimes when Basel-III type capital regulations are applied. Given the non-negligible effects of Basel II-type bank capital regulations on equilibrium determinacy (when banks deviate from regulatory capital ratio targets as per Benes and Kumhof (2015)) we need to explore the possibility of *countercyclical* regulations to support monetary policy in ensuring equilibrium uniqueness. By placing the spotlight on the need to reduce the procyclical effects of bank capital regulation under Basel II, the new policy paradigm encourages more restricted lending in economic booms and a relaxed one in downturns.[18] In this spirit, Basel III regulatory measures enforce banks to hold countercyclical bank capital buffers.[19]

Proposition 5. When monetary authorities focus entirely on controlling inflation and countercyclical capital regulations are at work, there exists a unique bounded REE if and only if:

$$i)\ 1 < \varphi_\Pi < \varphi_3 \equiv \frac{2\sigma(1+\beta)+k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)+\Xi\chi_V]}{k[2\sigma F-\sigma-\varphi-\Xi(1+\varphi+\sigma-K_2+2\sigma K_3+\chi_V)]},\ for\ \ v < v_1^* \tag{52}$$

$$ii)\ 1 < \varphi_\Pi < \varphi_4 \equiv \frac{\sigma(1-\beta)}{k[-\sigma-\varphi-\Xi(1+\varphi+\sigma-K_2+\sigma K_3+\chi_V)+\sigma F]},\ for\ \ v > v_1^* \tag{53}$$

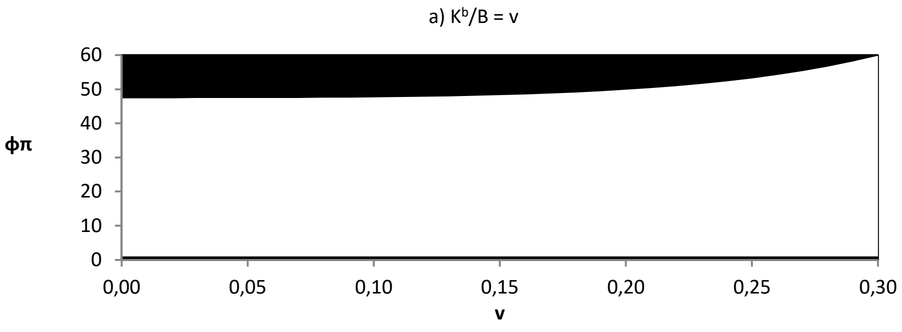
$$iii)\ \text{for}\ \sigma < \varphi\text{: i)}\ \varphi_\Pi > 1\ \text{ for } v < v_1^*\text{ , ii) ii) } 1 < \varphi_\Pi < \varphi_4 \text{ for } v > v_1^* \tag{54}$$

Proof. See Appendix 4.

As in our baseline case, i.e. strict inflation targeting with time-invariant regulatory capital ratio, there are two upper bounds on the inflation coefficient, namely φ_3 and φ_4. Both bounds are positively related to the degree of countercyclicality of capital requirements χ_V. For REE to be unique, aggressiveness in macroprudential policy should be associated with a monetary policy that is more aggressive towards inflation.

Proposition 6. Strict inflation targeting in conjunction with countercyclical bank capital buffers of Basel-III type improves the prospects for equilibrium uniqueness relative to capital regulations of Basel-II type.

Comparing Figure 2 with Figure 3 (especially panels b and c), we conclude that under Basel III regime there is no reason for concern for equilibrium multiplicity (for plausible parameter values of v and φ_Π and regardless the level of bank capital holdings in excess of regulatory limits).



[18] Implementation of the Basel III framework seems to have reduced lending (Ben Naceur et al. 2018).
[19] Banks do have incentives to manage capital buffers countercyclically (e.g. for efficiency reasons, as a signal to the market, or to avoid the costs associated with having to issue fresh equity). These incentives *per se* are, however, insufficient to eliminate the inherent pro-cyclicality of regulatory capital requirements (Repullo and Suarez 2013).

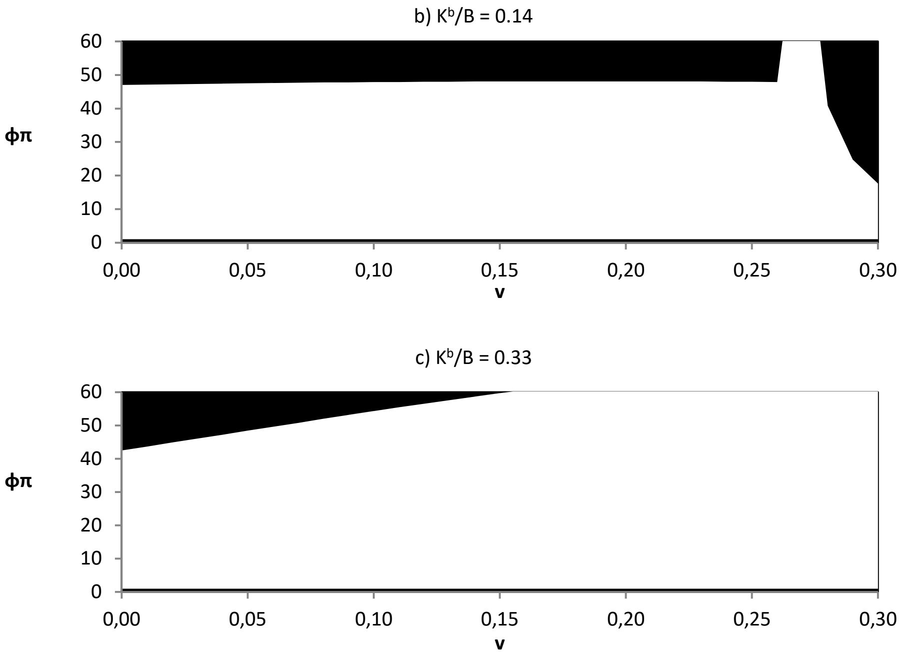


Figure 3. Determinacy, strict inflation targeting, and Basel-III type capital regulations.
Note: Simulations are based on baseline parameter values. Determinacy (white area). Indeterminacy (dark area).

In the numerical analysis that follows in Figure 4, we plot the determinacy regions in the plane (φ_{Π}, v) for four alternative values of χ_V: 0, 0.5 (our baseline case), 1, and 1.5. Notice that the upwards shifts of the upper bounds, as χ_V increases, expand the determinacy region for empirically plausible interest rate responses. Hence, the presence of countercyclical Basel III-type capital regulations ($\chi_V \neq 0$) expands the determinacy region compared to Basel II-type settlements ($\chi_V = 0$).

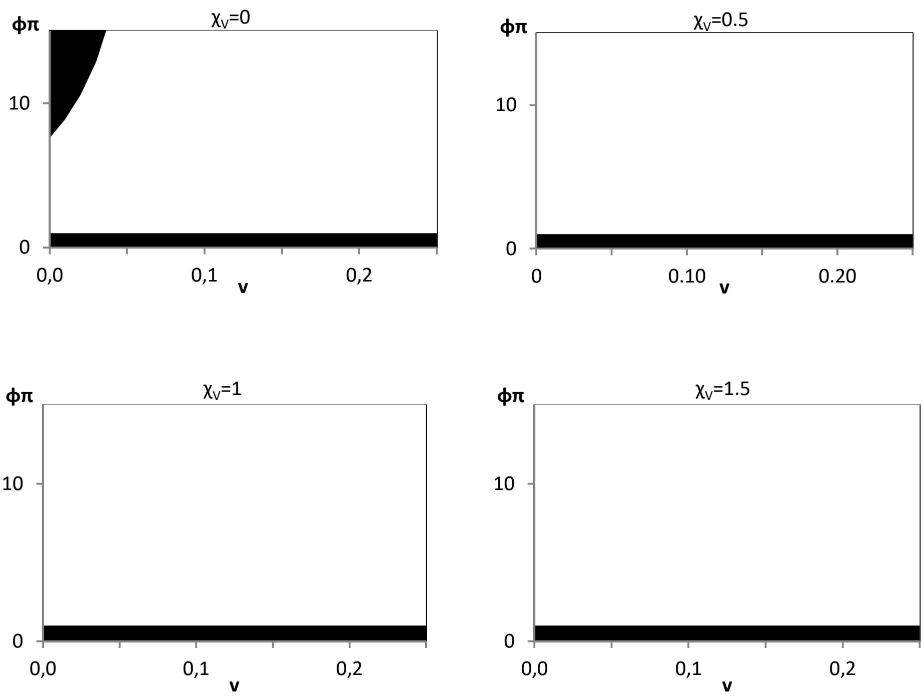


Figure 4. Determinacy and the role of capital regulations countercyclicality under strict inflation targeting.
Note: Simulations are based on baseline parameter values. Determinacy (white area). Indeterminacy (dark area).

The beneficial impact of countercyclical capital buffers – from the vantage of equilibrium uniqueness – is also related to the fact that countercyclical capital buffers restore determinacy for excessive bank capital holdings $K^b/B = 0.33$ and for every value of v. Intuitively, let us assume a non-fundamental increase in inflation. The presence of countercyclical capital buffers restricts the cost channel effect. In particular, due to the negative effect of the policy rate increase on the demand for goods, the bank capital-asset ratio falls, inducing banks to decrease the lending rate as banks now adjust lending standards in response to time-varying capital requirements (equation (46)). This, in turn, shifts the supply for credit, thereby weakening the cost channel, and through the optimal loan rate setting (equation (47)), impedes inflation expectations to become self-fulfilling.

Satisfying the Taylor principle with an upper bound, however, ceases to be true once $\sigma < \varphi$ as in Llosa and Tuesta (2009). In this case, condition (54) shows that the upper bound disappears, rendering v and K^b/B completely irrelevant for determinacy.

3.2 Flexible inflation targeting and Basel-type capital regulations regimes

We now consider the determinacy implications for our economy if the output gap is also included in the interest-rate feedback rule (flexible inflation targeting regime), under time-invariant (Section 3.2.1) and countercyclical capital regulations (Section 3.2.2). Hence, we explore the possibility of additional targets in the central bank's reaction function to alleviate the aforementioned problems of shrinking determinacy. For our simulation exercises, we follow Taylor (1993) and adopt the value $\varphi_Y = 0.125$.

3.2.1 Flexible inflation targeting and Basel-II type capital regulations

Proposition 7. Under the Taylor rule and the cost channel driven by time-invariant capital regulations, the necessary and sufficient conditions for determinacy are given by:

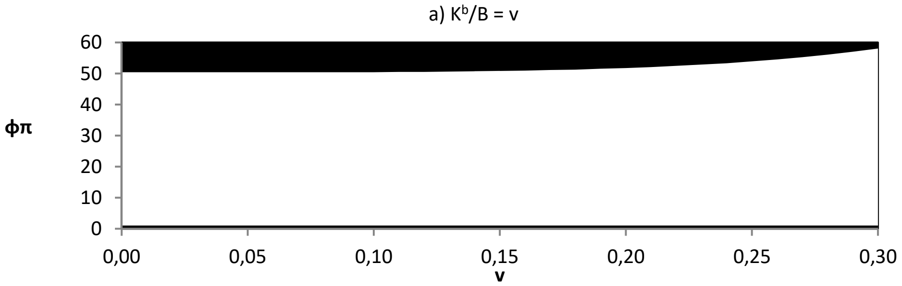
i) $\varphi_6 \equiv 1 + \frac{kF-(1-\beta)-k\Xi K_3}{k\{\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)\}}\varphi_Y < \varphi_\Pi < \varphi_7 \equiv \frac{\sigma(1-\beta)+\varphi_Y}{k\{\sigma F-\sigma-\varphi-\Xi(1+\varphi+\sigma+\sigma K_3-K_2)\}}$, for $v < v_1$ (55)

ii) $\varphi_6 \equiv 1 + \frac{kF-(1-\beta)-k\Xi K_3}{k\{\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)\}}\varphi_Y < \varphi_\Pi < \varphi_5 \equiv \frac{2\sigma(1+\beta)+k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)]+(1+\beta+kF-k\Xi K_3)\varphi_Y}{k\{2\sigma F-\sigma-\varphi-\Xi(1+\varphi+\sigma+2\sigma K_3-K_2)\}}$,
for $v > v_1$ (56)

Proof. See Appendix 5.

Comparing Figure 2 with Figure 5 (panels b and c), verifies the improvement in determinacy terms when the monetary authority adopts flexible inflation targeting (relative to strict inflation targeting). In this case, even though bank capital holdings exceed the regulatory targets, the region of (φ_Π, v) space associated with the determinacy of equilibrium is significantly enlarged for all values of K^b/B.

a) $K^b/B = v$



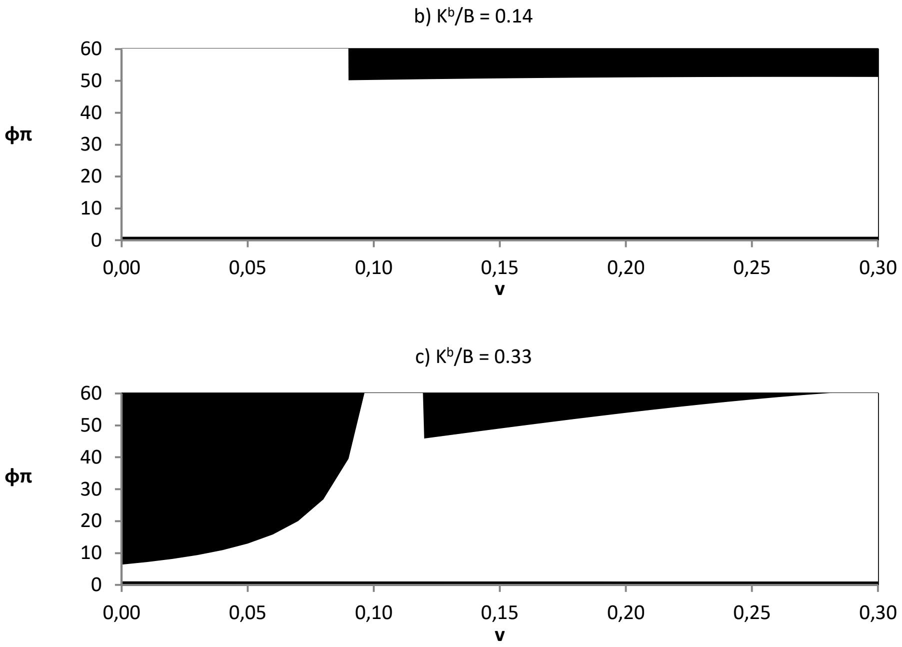


Figure 5. Determinacy, flexible inflation targeting, and Basel-II type capital regulations.
Note: Simulations are based on baseline parameter values. Determinacy (white area). Indeterminacy (dark area).

Proposition 8: Flexible inflation targeting is more effective in ensuring a unique REE than strict inflation targeting when tight bank capital regulations of Basel-II type are at work.

The explanation is again twofold. First, the upper bound is more relaxed under flexible inflation targeting than the corresponding one under strict inflation targeting, thereby increasing the probability of avoiding any intersection with the lower bound and attaining a determinate equilibrium. Indeed, for $= 0.06$, $K^b/B = 0.3$, and $\varphi_Y = 0.5$ the determinacy range is given by $1.12 < \varphi_\Pi < 15.82$, whereas $\varphi_Y = 0$ yields $1 < \varphi_\Pi < 1.17$. Second, responding to both inflation and output restores determinacy for all values of v when $K^b/B = 0.33$.

Therefore, in the presence of time-invariant capital regulations, the economy is *less* prone to indeterminacy under flexible inflation targeting than when the central bank reacts exclusively to inflation. This finding challenges the conventional view of the cost channel literature positing that targeting output is less likely to induce self-fulfilling equilibrium (Surico 2008). Our finding is driven by the fact that the more moderate rise in monetary policy rate[20] weakens the cost channel. In addition, stricter bank capital regulations hamper interest rate pass-through, thus increasing the possibility of REE determinacy.

Two additional findings emerge: First, there is a complementarity between φ_Π and φ_Y reflected in both the lower bound φ_6 and the upper bounds φ_5 and φ_7. We opt for concentrating on φ_6 as we are mostly interested in empirically plausible policy coefficient values.[21] In particular, the policy coefficient complementarity is explained as follows: since the presence of the cost channel results in a downward-sloping long-run Phillips curve, that is, $dy/d\pi = (1 - \beta - kF + \kappa\Xi v\varphi_\Pi)/\{k(\sigma + \varphi) + k\Xi X[r(1 + \sigma + \varphi) - v\varphi_Y]\} < 0$[22] in conditions (55) and (56), the traditional trade-off between φ_Π and φ_Y under the standard model without the cost channel (Clarida et al. 2000; Woodford 2003)

[20] If the central bank responds to the output gap as well, the nominal interest rate hike will be less compared to strict inflation targeting.

[21] Based on baseline parameter values, for $v < v_1 = 0.09$, i.e. $v = 0.05$, the upper bound is equal to 235 ($K^b/B = 0.14$), whereas for $v > v_1$, i.e. $v = 0.1$, the bound drops to 49.7. Even though shifts in the upper bounds (due to changes of v) are far more quantitatively important than the shifts of φ_6 the implied policy coefficient values are too high to be supported by empirical evidence.

[22] By using the long-run version of equations (39), (40), (42), and (43), i.e. $\pi_t = E_t\pi_{t+1} = \pi$, $y_t = E_t y_{t+1} = y$, and $r_t = r$, $r_t^L = r^L$, $lev_t = lev$, $v_t = v$, and assuming δ=1 equation (40) reduces to $\{k(\sigma + \varphi) + k\Xi X[r(1 + \sigma + \varphi) - v\varphi_Y]\}y = (1 - \beta - kF + \kappa\Xi v\varphi_\Pi)\pi$.

disappears.[23] More interestingly, in our setting, this complementarity between policy coefficients is decreasing in v, that is, the lower bound φ_6 negatively depends on v (Figure 6). As such, an aggressive central bank towards output should be stricter on inflation with a loosening of prudential requirements. Indeed, this upgrades the role of φ_Y which is largely neglected in the literature on the aggregate demand channel of monetary transmission[24] (Clarida et al. 2000; Woodford 2003).

Second, under benchmark parameterization, changes of v exert a non-negligible (negative) impact on the lower bound φ_6 and hence on the determinacy area (Figure 6). The opposite result holds for larger deviations of bank capital holdings from the required levels.

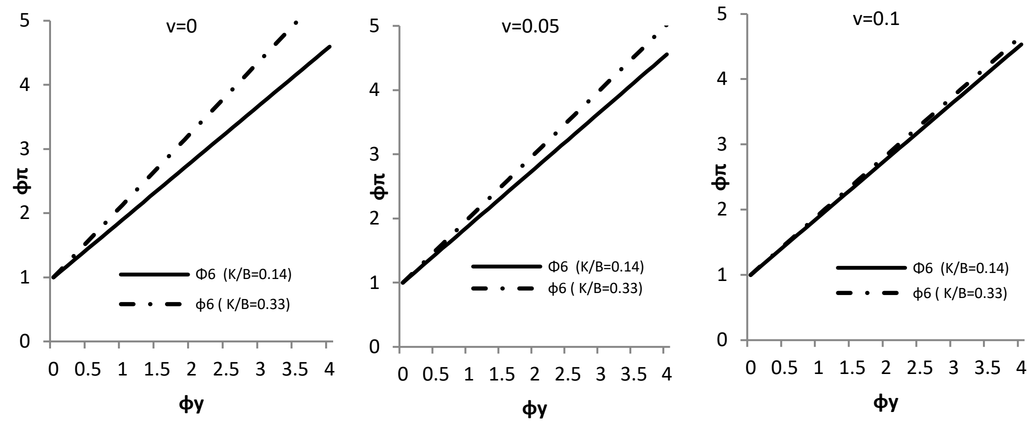


Figure 6. Determinacy and the role of fixed capital regulations in flexible inflation targeting regime.
Note: Simulations are based on baseline parameter values. Determinacy (white area). Indeterminacy (dark area).

3.2.2 Flexible inflation targeting and Basel-III type capital regulations

This sub-section focuses on the effects of countercyclical regulations, as proposed by Basel III, on the properties of determinacy equilibrium when the central bank aims at stabilizing both inflation and output gap.

Proposition 9. Under flexible inflation targeting, when both time-invariant and countercyclical capital regulations are at work, the necessary and sufficient conditions for determinacy are given by:

$$\varphi_8 \equiv 1 + \frac{kF-(1-\beta)-k\Xi K_3}{k\{\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2+\chi_V)\}}\varphi_Y < \varphi_\Pi < \varphi_9 \equiv \frac{2\sigma(1+\beta)+k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2+\chi_V)]+(1+\beta+kF-k\Xi K_3)\varphi_Y}{k\{2\sigma F-\sigma-\varphi-\Xi(1+\varphi+\sigma+2\sigma K_3-K_2+\chi_V)\}},$$

for $\forall v$ (57)

Proposition 10. Flexible inflation targeting, in conjunction with countercyclical bank capital buffers, exerts a stabilizing effect on the REE when banks are required to meet time-invariant capital standards.

Two justifications are provided for this result. First, combining flexible inflation targeting rules with financial regulations incorporating a macroprudential dimension (e.g. equation (46)) greatly raises the upper bound on the inflation coefficient (Figure 7, panels b and c) relative to the case of strict inflation targeting (Figure 2, panels b and c). For $= 0.04$, $\varphi_Y = 0.5$, and $\chi_V = 0.5$ the bound φ_9 is equal to 57.06 (K^b/B = v), 57.13 (K^b/B = 0.14), 56.87 (K^b/B = 0.33). In contrast, $\varphi_Y = 0$ and $\chi_V = 0$ (benchmark case) render φ_8 equal to 47.06 (K^b/B = v), 16.3 (K^b/B =0.14) and REE indeterminate when K^b/B = *0.33*. Second, except for the expansion of the determinacy region relative to the case of strict

[23] In the standard model without the cost channel, condition (55) becomes $1 - \frac{(1-\beta)\varphi_Y}{k(\sigma+\varphi)} < \varphi_\Pi$, where $\frac{(1-\beta)}{k(\sigma+\varphi)}$ is the slope of the NKPC in the long run. This condition implies a trade-off between φ_Π and φ_Y; values of $\varphi_\Pi < 1$ may still ensure determinacy provided the central bank responds more aggressively to output. The presence of the cost channel overturns this trade-off. In the case with no capital regulations, the slope of the NKPC in the long run equals $dy/d\pi = (1-\beta-k)/k(\sigma+\varphi) < 0$.

[24] It is neglected because the subjective discount factor is calibrated very close to one, and thus, the coefficient $(1-\beta)/k(\sigma+\varphi)$ is approximately zero.

inflation targeting, flexible inflation targeting in conjunction with countercyclical bank capital buffers restore determinacy for large deviations of bank capital holdings from regulatory targets, i.e. when $K^b/B = 0.33$.

The intuition is based on two points and it is easy to grasp. As already explained (see Sections 3.1.2 and 3.2.1), the incorporation of the output gap as an additional targeting variable weakens the cost channel, and the presence of countercyclical capital buffers strenghtens the bank-leverage channel and the typical demand channel. These two effects together prevent self-fulfilling expectations of higher inflation.

These results broadly accord with N'Diaye's (2009) claim that leaning against a financial accelerator process, countercyclical macroprudential policies can support monetary policy authorities in pursuing their objectives.

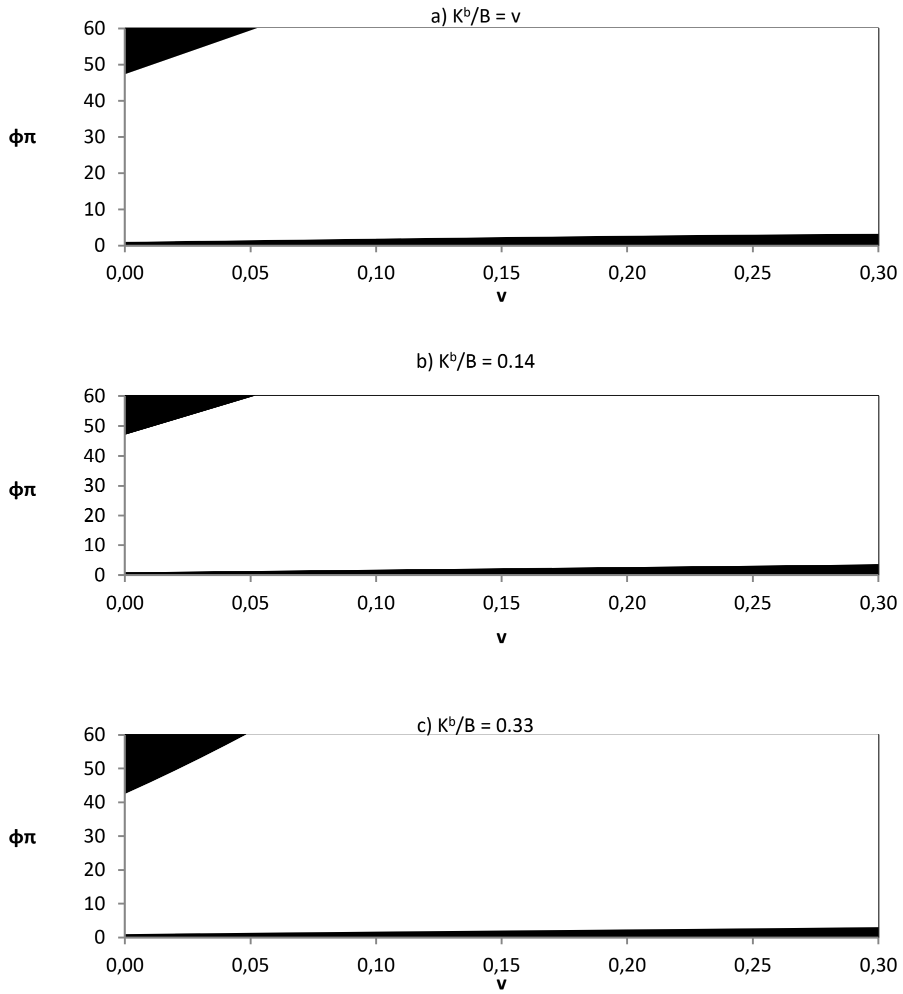


Figure 7. Determinacy and the role of time-variant capital regulations in flexible inflation targeting regime.
Note: Simulations are based on baseline parameter values. Determinacy (white area). Indeterminacy (dark area).

Another interesting finding is the strong positive impact of a tightening of fixed capital regulations v on the lower bound φ_8 for empirically plausible values of φ_Π (Figure 8).

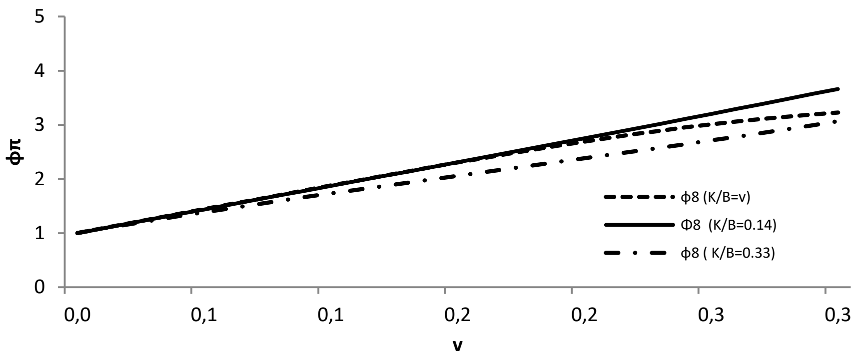


Figure 8. Determinacy and the role of fixed and time-variant capital regulations in flexible inflation targeting.

4 Concluding Remarks

A key issue for evaluating monetary policy rules is whether they determine a rational expectations equilibrium or not. This paper contributes to the active literature on the impact of the cost channel of monetary policy on equilibrium determinacy in New Keynesian models. Deviating from existing literature, we focus on financial regulations with a macroprudential dimension as we believe that this significantly enhances the realism of those models. To the best of our knowledge, prior works ignore the role of regulatory capital requirements and excess bank capital holdings in the determination of REE, and this may be viewed as a void in New Keynesian models.

By introducing bank balance sheets with capital, as per Gerali et al. (2010), we assess the implications for the determinacy of REE, and thus the robustness of the Taylor principle, under different prudential regulatory regimes affecting bank capital. The intuition behind the important role of bank capital regulations in the uniqueness of REE is easy to grasp: bank capital regulations generate an additional monetary policy transmission channel, the bank-leverage channel, whereby changes in monetary policy rates, affect output, then bank leverage and finally inflation *via* changes in credit supply.

Our results show that the standard conditions ensuring REE uniqueness change. Under strict inflation-targeting policies, the size of the determinacy region expands considerably as time-invariant regulatory capital requirements increase. This outcome stems from credit market dynamics, particularly the cyclical patterns in bank leverage and limitations in interest rate adjustments. Conversely, bank capital ratios higher than mandated limits result in a significant reduction in the determinacy area. Additionally, maintaining *excessive* bank capital buffers can change dramatically the properties of inflation-targeting rules. In particular, inflation targeting may become susceptible to multiple equilibria that add, an often welfare-reducing, volatility to the system. A major contributing factor to these adverse results is bank capital procyclicality arising from the supply side of the credit markets. We postulate that an antidote to these problems is the introduction of countercyclical capital buffers and/or the conditioning of the monetary policy instrument on output since both exert a beneficial impact from the vantage of equilibrium uniqueness.

Conclusively, our analysis sheds further light on the stability properties of the inflation targeting regimes and the effectiveness of the Taylor principle, the *prima facie* criterion in assessing the monetary policy when bank capital regulations affect credit supply and banks are overcapitalised. We can obtain a number of important policy implications from our findings. First, strict requirements not only enhance banking system stability but they also widen predictable or controllable policy outcomes across various economic scenarios. Thus, policymakers may more effectively use monetary policy tools to achieve desired inflation and output targets. Second, a trade-off exists between maintaining higher bank capital ratios and the effectiveness of inflation-targeting policies. Policymakers need to carefully balance these objectives to ensure financial stability, more predictable outcomes, and effective monetary policy transmission. Third, excessive bank capital reserves might introduce volatility and susceptibility to multiple equilibria, thus harming overall welfare. This suggests that overcapitalization might inadvertently introduce instability, contrary to the intended purpose of stability. As such, policymakers need to carefully navigate the interplay between higher bank capital ratios (aimed at ensuring financial stability) and the potential limitations that these ratios might pose on the effectiveness of inflation-targeting policies. Fourth, countercyclical bank capital regulations, as well as a more balanced approach targeting both inflation and output, enhance the ability to implement effective monetary policies during economic fluctuations. In sum, our findings underscore the need to incorporate bank capital requirements, bank capital holdings, and credit market cycles in the design of appropriate interest rate rules and call for a coordinated approach to policy-making as a prerequisite for achieving overall macroeconomic stability.

Declarations

Conflicts of Interest The authors declare that there is no confict of interest associated with this publication, and that there has been no fnancial support for this work that could have infuenced its outcome.

Appendices

Appendix 1

Banks' balance sheet constraint states that banks can finance their loans using either deposits or bank capital. Log-linearization of the banks' balance sheet constraint and solving for deposits yields:

$$d_t = \frac{1}{1-v} b_t - \frac{v}{1-v} k_t^b$$

In addition, the working capital hypothesis implies that $b_t = w_t^r + h_t$ where w_t^r denotes the real wage and h_t the hours worked. Substituting $y_t = h_t$ and households optimality condition $w_t^r = (\sigma + \varphi) y_t$ in $b_t = w_t^r + h_t$ leads to a modified working capital constraint:

$$b_t = (\varphi + \sigma + 1) y_t$$

Substituting $j_t^b = \frac{r+spr+k_{kb}v^3}{rv+spr} b_t - \frac{r}{rv+spr} d_t + \frac{v}{rv+spr} r_t - \frac{k_{kb}v^3}{rv+spr} k_t^b$ into the log-linearised version of equation (26), that is, $k_t^b = (1-\delta) k_{t-1}^b + \delta j_t^b$, we eliminate j_t^b.

Then, we substitute the first two equations for d_t and b_t.

$$k_t^b = \frac{(1-v)(rv+spr)}{(rv+spr+\delta k_{kb}v^3)(1-v)-\delta rv} (1-\delta) k_{t-1}^b + \frac{(r+spr+k_{kb}v^3)\delta(1-v)-\delta r}{(rv+spr+\delta k_{kb}v^3)(1-v)-\delta rv} (\varphi+\sigma+1) y_t + \frac{(1-v)\delta v}{(rv+spr+\delta k_{kb}v^3)(1-v)-\delta rv} r_t$$

Substracting the variable k_t^b from (both sides of) $b_t = (\varphi + \sigma + 1) y_t$ and using the definition $lev_t \equiv b_t - k_t^b$ we get that:

$$lev_t = (\varphi + \sigma + 1) y_t - k_t^b$$

Finally, substituting the previous equation for k_t^b and the interest rate rule, equation (44) or (45) leads to equation (43) in the text.

Appendix 2

Equations (39),(40),(42),(43), and (44) is the system of difference equations describing the equilibrium dynamics of our economy. After some algebraic substitutions, we can reduce the system to one involving two variables. In particular, we substitute equations (42) and (43) into equation (40) and equation (44) into equations (39) and (40) and then write the model in the state space form $AE_t z_{t+1} = Bz_t$ where z_t is the 2x1 vector of the endogenous variables which are non-predetermined $z_t = [y_t,\ \pi_t]'$. The 2x2 square matrices of the coefficients are defined as:

$$A \equiv \begin{bmatrix} 1 & \frac{1}{\sigma} \\ 0 & \frac{\beta}{1-(F-\Xi K_3)k\varphi_\Pi} \end{bmatrix} \text{ and } B \equiv \begin{bmatrix} 1 & \frac{\varphi_\Pi}{\sigma} \\ -\frac{k(\sigma+\varphi)+k\Xi(1+\varphi+\sigma-K_2)}{1-(F-\Xi K_3)k\varphi_\Pi} & 1 \end{bmatrix}$$

Since, under baseline calibration, matrix A is invertible, we get that $E_t z_{t+1} = A^{-1} B z_t = \Gamma z_t$, where $\Gamma \equiv A^{-1} B$.

$$\Gamma = \begin{bmatrix} 1+\frac{k(\sigma+\varphi)+k\Xi(1+\varphi+\sigma-K_2)}{\sigma\beta} & \frac{\beta\varphi_\Pi-[1-(F-\Xi K_3)k\varphi_\Pi]}{\beta\sigma} \\ -\frac{k(\sigma+\varphi)+k\Xi(1+\varphi+\sigma-K_2)}{\beta} & \frac{1-(F-\Xi K_3)k\varphi_\Pi}{\beta} \end{bmatrix}$$

By simple algebra, we have that the determinant and trace of matrix Γ are given by, respectively:

$$det(\Gamma) = \frac{1-(F-\Xi K_3)k\varphi_\Pi}{\beta} + \frac{k(\sigma+\varphi)+k\Xi(1+\varphi+\sigma-K_2)}{\sigma\beta}\varphi_\Pi$$

$$trace(\Gamma) = 1+\frac{k(\sigma+\varphi)+k\Xi(1+\varphi+\sigma-K_2)}{\sigma\beta}+\frac{1-(F-\Xi K_3)k\varphi_\Pi}{\beta}$$

For determinacy, the number of eigenvalues of Γ outside the unit circle must equal the number of non-predetermined endogenous variables (Blanchard and Kahn 1980). In our case, there are two non-predetermined endogenous variables, inflation and output. Following Woodford (2003), this condition is satisfied if and only if either Case I or Case II below is true.

Case I:

$$det\,\Gamma > 1 \quad \text{(A.1)}$$

$$det\,\Gamma - tr\Gamma > -1 \quad \text{(A.2)}$$

$$det\,\Gamma + tr\Gamma > -1 \quad \text{(A.3)}$$

Case II:

$$det\,\Gamma - tr\Gamma < -1 \quad \text{(A.4)}$$

$$det\,\Gamma + tr\Gamma < -1 \quad \text{(A.5)}$$

Consider Case I. Let us first focus on (A.1) which translates into $k\varphi_\Pi[\sigma+\varphi+\Xi(1+\varphi+\sigma)-\Xi K_2-\sigma(F-\Xi K_3)] > -\sigma(1-\beta)$. To isolate φ_Π on the LHS, we need to divide both sides of the inequality by $\sigma+\varphi+\Xi(1+\varphi+\sigma)-\Xi K_2-\sigma(F-\Xi K_3)$. Thus, for $\sigma+\varphi+\Xi(1+\varphi+\sigma)-\Xi K_2-\sigma(F-\Xi K_3)>0$, $v > v_1$, we get $\varphi_\Pi > -\sigma(1-\beta)/k[\sigma+\varphi+\Xi(1+\varphi+\sigma)-\Xi K_2-\sigma(F-\Xi K_3)]$, The resulting condition is nested in

$$\varphi_\Pi > 0 \quad \text{(A.6)}$$

In the alternative case, i.e. for $v < v_1$ and thus $\sigma+\varphi+\Xi(1+\varphi+\sigma)-\Xi K_2-\sigma(F-\Xi K_3)<0$, we get:

$$\varphi_\Pi < \varphi_2 \equiv \sigma(1-\beta)/k[-\sigma-\varphi-\Xi(1+\varphi+\sigma-K_2+\sigma K_3)+\sigma F] \quad \text{(A.7)}$$

We now consider (A.2). This condition leads to $\varphi_\Pi k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)] > k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)]$. For every value of v we have that $\sigma+\varphi+\Xi(1+\varphi+\sigma)-\Xi K_2>0$ and thereby (A.2) translates into:

$$\varphi_\Pi > 1 \quad \text{(A.8)}$$

Condition (A.3) leads to $\varphi_\Pi k\{-2\sigma F+\sigma+\varphi+\Xi(1+\sigma+\varphi+2\sigma K_3-K_2)\} > -\{2\sigma(1+\beta)+k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)]\}$. Again, we have to evaluate the sign of $-2\sigma F+\sigma+\varphi+\Xi(1+\sigma+\varphi+2\sigma K_3-K_2)$. This turns out to be positive for every value of v and $\sigma<\varphi$. Otherwise, this expression is negative. The assumption $\sigma>\varphi$ corresponds to a situation in which the weight of the cost channel of monetary policy transmission is relatively larger than the weight of the demand channel. In the latter case, an explicit condition for φ_Π is the following:

$$\varphi_\Pi < \varphi_1 \equiv \frac{2\sigma(1+\beta)+k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)]}{k[2\sigma F-\sigma-\varphi-\Xi(1+\sigma+\varphi-2\sigma K_3+K_2)]} \quad \text{(A.9)}$$

Putting things together, for $\sigma>\varphi$ we can reduce the three inequalities in Case I to $max\{0,1\}<\varphi_\Pi<\varphi_1$ for $v>v_1$. Equation (49) from Proposition 2 then follows immediately. Otherwise, for $v<v_1$ we have that $1<\varphi_\Pi<min\{\varphi_1,\varphi_2\}$. This results in equation (48) in the text.

Appendix 3

The upper bound on the inflation coefficient φ_2 intersects with the lower bound, and thus determinacy is never attained when $\sigma(1-\beta)/k[-\sigma-\varphi-\Xi(1+\varphi+\sigma-K_2+\sigma K_3)+\sigma F]=1$. The latter holds for $K^b/B=0.33$ and $v<v_2=0.06$. Note that we concentrate on the upper bound φ_2 and not on φ_1 since we are interested in empirically plausible values of the inflation coefficient. For instance, under baseline parameterization, $\varphi_1 \in (31.73,\ 37.25)$.

Appendix 4

Considering equation (46) with equations (39),(40),(42), and (43), the reduced-form equilibrium system $E_t z_{t+1} = A^{-1}Bz_t = \Gamma z_t$ is characterized by the system matrix Γ:

$$\Gamma = \begin{bmatrix} 1+\dfrac{k(\sigma+\varphi)+k\Xi(1+\varphi+\sigma-K_2+\chi_V)}{\sigma\beta} & \dfrac{\beta\varphi_\Pi-[1-(F-\Xi K_3)k\varphi_\Pi]}{\beta\sigma} \\ -\dfrac{k(\sigma+\varphi)+k\Xi(1+\varphi+\sigma-K_2+\chi_V)}{\beta} & \dfrac{1-(F-\Xi K_3)k\varphi_\Pi}{\beta} \end{bmatrix}$$

Its determinant and trace are given by, respectively:

$$det(\Gamma) = \frac{1-(F-\Xi K_3)k\varphi_\Pi}{\beta} + \frac{k(\sigma+\varphi)+k\Xi(1+\varphi+\sigma-K_2+\chi_V)}{\sigma\beta}\varphi_\Pi$$

$$trace(\Gamma) = 1 + \frac{k(\sigma+\varphi)+k\Xi(1+\varphi+\sigma-K_2+\chi_V)}{\sigma\beta} + \frac{1-(F-\Xi K_3)k\varphi_\Pi}{\beta}$$

From an argument similar to that in the proof of Proposition 1, the necessary and sufficient condition for local determinacy of REE is that the number of eigenvalues of Γ outside the unit circle must equal the number of non-predetermined endogenous variables. By Proposition C.1 of Woodford (2003), this is the case if and only if either Case I or Case II is satisfied. We start deriving policy parameter restrictions from (A.1). We can write the latter as $\varphi_\Pi k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2+\sigma K_3+\chi_V)-\sigma F] > -\sigma(1-\beta)$. We have to distinguish two cases. First, for $\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2+\sigma K_3+\chi_V)-\sigma F>0$, which holds for $v<v_1^*$, we have that $\varphi_\Pi > -\sigma(1-\beta)/k[\,\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2+\sigma K_3+\chi_V)-\sigma F]$. From the latter inequality, we get:

$$\varphi_\Pi > 0 \tag{A.10}$$

Second, for $v>v_1^*$, we get that in terms of the inflation equation:

$$\varphi_\Pi < \varphi_4 \equiv \frac{\sigma(1-\beta)}{k[-\sigma-\varphi-\Xi(1+\varphi+\sigma-K_2+\sigma K_3+\chi_V)+\sigma F]} \tag{A.11}$$

Next, we derive restrictions for φ_Π from the condition (A.2). This condition implies that $\varphi_\Pi k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2+\chi_V)] > k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2+\chi_V)]$. Since $\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)>0$, the term $\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2+\chi_V)$ is also positive. Therefore, the parameter restriction derived from fulfillmenting (A.2) is:

$$\varphi_\Pi > 1 \tag{A.12}$$

Condition (A.3) leads to $\varphi_\Pi k\{-2\sigma F+\sigma+\varphi+\Xi(1+\sigma+\varphi+2\sigma K_3-K_2+\chi_V)\} > -\{2\sigma(1+\beta)+k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2+\chi_V)]\}$. The term $-2\sigma F+\sigma+\varphi+\Xi(1+\sigma+\varphi+2\sigma K_3-K_2)$ is is negative for every value of v and for $\sigma>\varphi$ (baseline assumption). In this case the upper bound for φ_Π is equal to:

$$\varphi_\Pi < \varphi_3 \equiv \frac{2\sigma(1+\beta)+k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2+\chi_V)]}{k[2\sigma F-\sigma-\varphi-\Xi(1+\sigma+\varphi-2\sigma K_3+K_2+\chi_V)]} \tag{A.13}$$

Equation (52) stated in Proposition 5 follows after combining conditions (A.10), (A.12), and (A.13), for example, $max\{0,1\}<\varphi_\Pi<\varphi_3$, whereas the combination of (A.11), (A.12), and (A.13) yields $1<\varphi_\Pi<min\{\varphi_3,\varphi_4\}$. The latter results in equation (53) in the text.

Finally, when $\sigma < \varphi$, we obtain $max\{0\,,1\} < \varphi_{\Pi} < \varphi_4$ for $v > v_1^*$ and $\varphi_{\Pi} > 1$ for $v < v_1^*$. Thus, the last part of Proposition 5, i.e. equation (54), follows immediately.

Appendix 5

The dynamic system $E_t z_{t+1} = A^{-1}Bz_t = \Gamma z_t$ is now defined by equations (39),(40),(42),(43), and equation (45). The matrix Γ is given by:

$$\Gamma = \begin{bmatrix} 1 + \frac{1}{\sigma}\varphi_Y + \frac{k(\sigma+\varphi+F\varphi_Y) + k\Xi(1+\varphi+\sigma-K_2-K_3\varphi_Y)}{\sigma\beta} & \frac{\beta\varphi_{\Pi} - [1-(F-\Xi K_3)k\varphi_{\Pi}]}{\beta\sigma} \\ -\frac{k(\sigma+\varphi+F\varphi_Y) + k\Xi(1+\varphi+\sigma-K_2-K_3\varphi_Y)}{\beta} & \frac{1-(F-\Xi K_3)k\varphi_{\Pi}}{\beta} \end{bmatrix}$$

With

$$det(\Gamma) = \frac{1-(F-\Xi K_3)k\varphi_{\Pi}}{\beta} + \frac{\varphi_Y[1-(F-\Xi K_3)k\varphi_{\Pi}]}{\sigma\beta} + \frac{\varphi_{\Pi}k[\sigma+\varphi+F\varphi_Y+\Xi(1+\varphi+\sigma-K_2-K_3\varphi_Y)]}{\sigma\beta}$$

$$trace(\Gamma) = 1 + \frac{1}{\sigma}\varphi_Y + \frac{k[\sigma+\varphi+F\varphi_Y+\Xi(1+\varphi+\sigma-K_2-K_3\varphi_Y)]}{\sigma\beta} + \frac{1-(F-\Xi K_3)k\varphi_{\Pi}}{\beta}$$

The system has two non-predetermined variables, and therefore, the system will have unique rational expectations equilibrium if, and only if, Case I or Case II is satisfied. Consider Case I. Condition (A.1) corresponds to $[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)-\sigma(F-\Xi K_3)]k\varphi_{\Pi} > -[\sigma(1-\beta)+\varphi_Y]$ .We distinguish two cases. First, $\sigma+\varphi+\Xi(1+\varphi+\sigma)-\Xi K_2-\sigma(F-\Xi K_3) > 0$, which holds for $v > v_1$, condition (A.1) implies $\varphi_{\Pi} > -[\sigma(1-\beta)+\varphi_Y]/k[\sigma(1-F)+\varphi+\Xi(1+\varphi+\sigma-K_2+\sigma K_3)]$. From the latter inequality, we obtain:

$$\varphi_{\Pi} > 0 \quad \text{(A.14)}$$

Second, for $\sigma+\varphi+\Xi(1+\varphi+\sigma)-\Xi K_2-\sigma(F-\Xi K_3)$, i.e. $v < v_1$, condition (A.1) takes the form:

$$\varphi_{\Pi} < \varphi_7 \equiv [\sigma(1-\beta)+\varphi_Y]/k[\sigma(1-F)+\varphi+\Xi(1+\varphi+\sigma-K_2+\sigma K_3)] \quad \text{(A.15)}$$

Condition (A.2) is true if and only if $\varphi_{\Pi}k[\sigma+\varphi+\Xi(1+\varphi+\sigma)-\Xi K_2] > k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2-K_3\varphi_Y)+F\varphi_Y]-\varphi_Y(1-\beta)$. The LHS is always positive and thereby (A.2) corresponds to:

$$\varphi_{\Pi} > \varphi_6 \equiv 1 + \frac{kF-(1-\beta)-k\Xi K_3}{k\{\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)\}}\varphi_Y \quad \text{(A.16)}$$

We derive, next, restrictions for φ_{Π} from the condition (A.3) which can be written as $\varphi_{\Pi}k\{-2\sigma F+\sigma+\varphi+\Xi(1+\sigma+\varphi+2\sigma K_3-K_2)\} > -\{2\sigma(1+\beta)+k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)]+(1+\beta+kF-k\Xi K_3)\varphi_Y\}$. The term $-2\sigma F+\sigma+\varphi+\Xi(1+\sigma+\varphi+2\sigma K_3-K_2)$ turns out to be negative for every value of v and $\sigma > \varphi$ (baseline assumption). In this case, the LHS is negative. In this case, another bound for φ_{Π} is:

$$\varphi_{\Pi} < \varphi_5 \equiv \frac{2\sigma(1+\beta)+k[\sigma+\varphi+\Xi(1+\varphi+\sigma-K_2)]+(1+\beta+kF-k\Xi K_3)\varphi_Y}{k\{2\sigma F-\sigma-\varphi-\Xi(1+\varphi+\sigma+2\sigma K_3-K_2)\}} \quad \text{(A.17)}$$

Considering all the above, we can reduce the three inequalities in Case I to $max\{0,\varphi_6\} < \varphi_{\Pi} < \varphi_7$ for $v < v_1$. Equation (55) from Proposition 7 then follows immediately. Otherwise, for $v > v_1$ we have that $\varphi_6 < \varphi_{\Pi} < min\{\varphi_5,\ \varphi_7\}$. This results in equation (56).

Appendix 6

Consider the dynamic system defined by equations (39), (40), (43), (47), and (45) and written in space state for $AE_t z_{t+1} = Bz_t$. Since matrix A is invertible we have that $E_t z_{t+1} = A^{-1}Bz_t = \Gamma z_t$, where

$$\Gamma = \begin{bmatrix} 1 + \frac{\varphi_Y}{\sigma} + \frac{k[\sigma + \varphi + \varphi_Y F + \Xi(1 + \varphi + \sigma - K_2 + \chi_V - K_3\varphi_Y)]}{\sigma\beta} & \frac{\beta\varphi_\Pi - [1 - (F - \Xi K_3)k\varphi_\Pi]}{\beta\sigma} \\ -\frac{k[\sigma + \varphi + \varphi_Y F + \Xi(1 + \varphi + \sigma - K_2 + \chi_V - K_3\varphi_Y)]}{\beta} & \frac{1 - (F - \Xi K_3)k\varphi_\Pi}{\beta} \end{bmatrix}$$

and

$$det(\Gamma) = \frac{1 - (F - \Xi K_3)k\varphi_\Pi}{\beta} + \frac{\varphi_Y[1 - (F - \Xi K_3)k\varphi_\Pi]}{\sigma\beta} + \frac{k[\sigma + \varphi + \varphi_Y F + \Xi(1 + \varphi + \sigma - K_2 + \chi_V - K_3\varphi_Y)]}{\sigma\beta}$$

$$trace(\Gamma) = 1 + \frac{1}{\sigma}\varphi_Y + \frac{k[\sigma + \varphi + \varphi_Y F + \Xi(1 + \varphi + \sigma - K_2 + \chi_V - K_3\varphi_Y)]}{\sigma\beta} + \frac{1 - (F - \Xi K_3)k\varphi_\Pi}{\beta}$$

The system has two non-predetermined variables, and therefore, the system will have unique rational expectations equilibrium if, and only if, Case I or Case II is satisfied. Condition (A.1) from Case I leads to $[\sigma + \varphi + \Xi(1 + \varphi + \sigma - K_2 + \sigma K_3 + \chi_V) - \sigma F]k\varphi_\Pi > -[\sigma(1 - \beta) + \varphi_Y]$. For $\sigma + \varphi + \Xi(1 + \varphi + \sigma - K_2 + \sigma K_3 + \chi_V) - \sigma F > 0$, which holds for $v < v_1^*$, we obtain $\varphi_\Pi > -[\sigma(1 - \beta) + \varphi_Y]/k[\sigma + \varphi + \Xi(1 + \varphi + \sigma - K_2 + \sigma K_3 + \chi_V) - \sigma F]$. The resulting condition is nested in

$$\varphi_\Pi > 0 \tag{A.18}$$

In the alternative case, i.e. for $v > v_1^*$ and thus $\varphi > \Xi(\sigma + \varphi - \chi_V) < 0$, condition (A.1) results in:

$$\varphi_\Pi < \varphi_{10} \equiv \frac{\sigma(1 - \beta) + \varphi_Y}{k[-\sigma - \varphi - \Xi(1 + \varphi + \sigma - K_2 + \sigma K_3 + \chi_V) + \sigma F]} \tag{A.19}$$

From condition (A.2) we find $\varphi_\Pi k[\sigma + \varphi + \Xi(1 + \varphi + \sigma - K_2 + \chi_V)] > k[\sigma + \varphi + \Xi(1 + \varphi + \sigma - K_2 + \chi_V)] + F\varphi_Y - (1 - \beta)\varphi_Y$. Since $\sigma + \varphi + \Xi(1 + \varphi + \sigma - K_2 + \chi_V)$ is always positive, the parameter restriction derived from fulfillmenting (A.2) is:

$$\varphi_\Pi > \varphi_8 \equiv 1 + \frac{kF - (1 - \beta) - k\Xi K_3}{k\{\sigma + \varphi + \Xi(1 + \varphi + \sigma - K_2 + \chi_V)\}}\varphi_Y \tag{A.20}$$

Condition (A.3) implies that $\varphi_\Pi k\{-2\sigma F + \sigma + \varphi + \Xi(1 + \sigma + \varphi + 2\sigma K_3 - K_2 + \chi_V)\} > -2\sigma(1 + \beta) - k[\sigma + \varphi + \Xi(1 + \varphi + \sigma - K_2 + \chi_V)] - (1 + \beta + kF - k\Xi K_3)\varphi_Y$. Since the term $-2\sigma F + \sigma + \varphi + \Xi(1 + \sigma + \varphi + 2\sigma K_3 - K_2 + \chi_V)$ is negative for $\sigma > \varphi$, the the upper bound for φ_Π is:

$$\varphi_\Pi < \varphi_9 \equiv \frac{2\sigma(1 + \beta) + k[\sigma + \varphi + \Xi(1 + \varphi + \sigma - K_2 + \chi_V)] + (1 + \beta + kF - k\Xi K_3)\varphi_Y}{k\{2\sigma F - \sigma - \varphi - \Xi(1 + \varphi + \sigma + 2\sigma K_3 - K_2 + \chi_V)\}} \tag{A.21}$$

Considering all the above, we can reduce the three inequalities in Case I to $max\{0, \varphi_8\} < \varphi_\Pi < \varphi_9$ for $v < v_1^*$. Otherwise, for $v > v_1^*$ we have that $\varphi_8 < \varphi_\Pi < min\{\varphi_9, \varphi_{10}\}$. This results in equation (57) in the text.

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