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Should Monetary Policy Lean against the Wind? An Evidence from a DSGE Model with Occasionally Binding Constraint

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Abstract:
This research paper studies the performance of the Taylor-type rules augmented with output and asset prices, and compares their performance in a model with an eternally and occasionally binding constraint. The rules are examined under the optimisation of a central bank's loss function and a welfare maximisation of the economic agents. The analysis delivers the following results. The model with occasionally binding constraint has more favourable properties regarding the hump-shaped and asymmetric impulse responses compared to the eternally binding constraint model. The best rule regarding the lowest value of the central banks' loss function proves to be the rule augmented with asset prices. The optimal reactions are, however, shock- and model-dependent. Moreover, a chosen specification of the loss function plays a significant role. The welfare maximisation reveals that reacting to asset prices might not be welfare-improving for both types of economic agents – households and entrepreneurs. This result is, however, model-dependent.

JEL Classification: E30, E44, E50
Keywords: asset prices, DSGE, leaning-against-the-wind, monetary policy, non-linearities, Taylor Rule

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1. Introduction

The augmented Taylor rules have been a subject of research for several decades since the prominent publication Taylor (1993). The author of that paper outlines a monetary policy rule according to which a central bank should set its policy rate. Since then, researchers tried to implement several types of variables into the basic Taylor rule to investigate whether these variables can carry useful information that should be directly reflected in the setting of the policy rate. The recent financial crisis of 2008 has shown that financial markets play a crucial role in macroeconomic fluctuations and that the interconnection between the real and the financial side of an economy is considerable. In accordance with this, the performance of the Taylor rules augmented with various financial variables started to be investigated.

There has been done a considerable amount of work in this field of research. A lot of models with a variety of sectors and modelling techniques have been introduced. For example, Svensson (2000) and Batini, Harrison, and Millard (2003) examine the performance of a battery of monetary policy rules in a small open economy context. Batini et al. (2003) illustrate that there is no suitable general rule and that the optimality of the rule is driven by the type of a shock. Schmitt-Grohé and Uribe (2007) investigate the implications of reacting to inflation and output in terms of welfare losses. Gambacorta and Signoretti (2014) demonstrate that reacting to asset prices brings macroeconomic benefits in terms of lower implied volatilities of inflation and output when the economy is driven by supply side shocks. Quint and Rabanal (2014) find that the introduction of a macroprudential policy rule could help reduce macroeconomic volatility. Chow, Lim, and McNelis (2014) show that the exchange rate rule has an advantage over a simple Taylor rule when the shocks are driven by foreign circumstances, while the simple Taylor rule is preferable in case of domestic shocks. On the other hand, Adolfson (2007) documents that a direct response to exchange rate contributes to lower welfare if the reaction coefficients are set to be sub-optimal.

The recent years have shown, however, that the linear models are not able to fully capture the non-linear dynamics that is present in the data and economic theory. The linearisation techniques remove second and high order interactions and also induce certainty equivalence property. Therefore, the models started to be augmented with non-linear features. These studies include for example the DSGE models with time-varying parameters (Tonner, Polanskỳ, and Vašíček, 2011), or the DSGE models with occasionally binding constraints. There are basically two approaches of how to model the occasionally binding constraint. The first one resides in the introduction of a penalty function as shown by Brzoza-Brzezina, Kolasa, and Makarski (2015) and the other one employs a first-order piecewise linear approximation technique introduced by Guerrieri and Iacoviello (2015). Since then, the number of research papers devoted to the non-linearities in the DSGE models is growing rapidly. The most recent contributions are for example Pietrunti (2017) or Guerrieri and Iacoviello (2017), in which the authors demonstrate how the linear approximations affect the recommendations for economic policy decision making.

We contribute to the existing research by comparing the performance of the Taylor-type rule augmented with asset prices with the rule accounting for changes in output in a DSGE model with occasionally binding constraint. To do so, we build on a closed economy model with financial sector introduced by Gambacorta and Signoretti (2014), and we modify the model by introducing the occasionally binding constraint via a penalty function approach in line with Brzoza-Brzezina et al. (2015). The model is then employed to compare the alternative monetary policy rules augmented with output and asset prices in terms of (a) a simple loss function and (b) in terms of the welfare maximisation. Our results show that the model with occasionally binding constraint has more plausible dynamics compared to the model with the eternally binding constraint regarding hump-shaped and asymmetric responses of the impulse response functions of the model variables. More importantly, we find that the rule augmented with asset prices can deliver better performance in terms of lower volatility of inflation and output compared to the standard rules reacting to developments in inflation and output. However, the results achieved under the model with the occasionally binding constraint are not so convincing as the results achieved under the eternally binding constraint variant.

The rest of the paper is organised as follows. Section 2 describes the models and introduces the occasionally binding constraint. Section 3 discusses calibration, the properties of the model and workings of the occasionally binding constraint. Section 4 is devoted to the optimal monetary policy rules, while section 5 studies the robustness of the results. Section 6 concludes.

2. The model

We modify a closed economy DSGE model Gambacorta and Signoretti (2014) who employ a simplified version of banking sector built by Gerali, Neri, Sessa, and Signoretti (2010). We add a non-liner feature of the model following Brzoza-Brzezina et al. (2015). In this section we first describe the structure of the baseline model without the non-linear feature and then we introduce a modification of the model that resides in the occasionally binding collateral constraints. We refer to the baseline model as the eternally binding constraint (EBC) model, while the augmented model is referred to as the occasionally binding constraint (OBC) model throughout the text.

The model outlined in this section characterisis an economy that is populated by two types of agents – patient households and impatient entrepreneurs. Patient households consume, provide labour, buy housing stock and make deposits in banks. Impatient entrepreneurs consume, hire labour, produce intermediate goods and take loans from banks in which they are constrainted by a limit. Production of goods relies on two sources - physical capital and labour input. Nominal rigidity is introduced into the model via the presence of retailers who face the adjustment cost à la Rotemberg (1982). The role of banks is to collect deposits from patient households at the policy rate and to issue loans to impatient entrepreneurs at the respective loan rate. It is assumed that the deposit market is perfectly competitive, while the loan market is monopolistically competitive. Banks also face an exogenous target capital-to-asset ratio. To close the model, the central bank is assumed to set its policy rate according to a Taylor-type rule. Following Gambacorta and Signoretti (2014), we assume that debts are indexed to current inflation to isolate the role of the financial frictions.

2.1. Patient households

Patient households choose consumption c_t^P, labour supply l_t^P and deposits d_t^P to maximise the utility function

$$\max_{\{c_t^P, d_t^P, l_t^P\}} E_0 \sum_{t=0}^{\infty} \beta_P^t \left[\log(c_t^P) - \frac{(l_t^P)^{1+\phi}}{1+\phi} \right] \tag{1}$$

subject to the budget constraint

$$c_t^P + d_t^P = w_t^P l_t^P + (1 + r_{t-1}^{ib}) d_{t-1}^P + J_t^P \tag{2}$$

where β_P^t is patient households' discount factor, ϕ is labour supply aversion, w_t^P is the real wage, r_t^{ib} is a net nominal policy rate which coincides with a net nominal deposit rate and $J_t^P = ((x_t - 1)/x_t) y_t$ represents real profits from ownership of retailers.

The optimisation results in the consumption-Euler equation

$$\frac{1}{c_t^P} = \beta_P E_t \left(\frac{1 + r_t^{ib}}{c_{t+1}^P} \right) \tag{3}$$

and the labour supply decision

$$\frac{w_t^P}{c_t^P} = (l_t^P)^{\phi}. \tag{4}$$

2.2. Entrepreneurs

Entrepreneurs maximise the utility function by choosing consumption c_t^E, labour supply l_t^P, capital K_t, and loans b_t^E

$$\max_{\{b_t^E, c_t^E, K_t, l_t^P\}} E_0 \sum_{t=0}^{\infty} \beta_E^t \log(c_t^E) \tag{5}$$

with respect to two budget constraints

$$c_t^E + q_t^k K_t + (1 + r_{t-1}^{bE}) b_{t-1}^E + w_t^P l_t^P = \frac{y_t}{x_t} + q_t^k (1-\delta) K_{t-1} + b_t^E, \tag{6}$$

$$b_t^E (1 + r_t^{bE}) = m_t^E E_t \left(q_{t+1}^k K_t (1-\delta) \right) \tag{7}$$

where β_E is entrepreneurs' discount factor such that $\beta_E < \beta_P$, c_t^E is consumption, r_t^{bE} is the net nominal loan rate, q_t^k is the real price of capital, δ is the depreciation rate of capital, x_t is the mark-up of the retailers, and m_t^E is the stochastic loan-to-value ratio. Entrepreneurs utilise in the production process a Cobb-Douglas production function of the form

$$y_t = a_t^E K_{t-1}^{\mu} (l_t^P)^{(1-\mu)} \tag{8}$$

where a_t^E is exogenous total factor productivity disturbance[1] and μ is a measure of capital input.

The optimisation problem yields the consumption-Euler equation

$$\frac{1}{c_t^E} = \beta_E E_t \left(\frac{1 + r_t^{bE}}{c_{t+1}^E} \right) + s_t^E (1 + r_t^{bE}), \tag{9}$$

the labour demand condition

$$w_t^P = (1-\mu) \frac{y_t}{l_t^P x_t} \tag{10}$$

and the investment-Euler equation

$$\frac{q_t^k}{c_t^E} = E_t \left(\frac{\beta_E}{c_{t+1}^E} \left(\frac{\mu y_{t+1}}{K_t x_{t+1}} + q_{t+1}^k (1-\delta) \right) + s_t^E m^E q_{t+1}^k (1-\delta) \right). \tag{11}$$

2.3. Capital producers

Capital producers combine undepreciated capital from the previous period with unsold final goods purchased from retailers as investment goods, I_t, to produce new stock of capital. Capital is subject to depreciation characterised by the depreciation rate δ. Moreover, the production of capital is subject to the adjustment cost parametrised by ψ^k. Therefore, the aggregate stock of capital evolves according to

$$K_t = (1-\delta) K_{t-1} + \left(1 - \frac{\psi^k}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 \right) I_t. \tag{12}$$

Capital producers choose the level of investment to maximise profits

$$\max_{\{I_t\}} \mathbb{E}_t \sum_{\tau=0}^{\infty} \Lambda_{t,t+\tau}^P \left[q_{t+\tau}^k \left(I_{t+\tau} - \frac{\psi^k}{2} \left(\frac{I_{t+\tau}}{I_{t+\tau-1}} - 1 \right)^2 I_{t+\tau} \right) - I_{t+\tau} \right] \tag{13}$$

where $\Lambda_{0,t}^P = \beta_P^{\tau} \lambda_0^P / \lambda_t^P$ is the real stochastic discount factor of patient households. The optimisation returns the Tobin's Q equation

$$1 = q_t^k \left[1 - \frac{\psi^k}{2} \left(\frac{I_t}{I_{t-1}} - 1 \right)^2 I_t - \psi^k \left(\frac{I_t}{I_{t-1}} - 1 \right) \frac{I_t}{I_{t-1}} \right] + \beta_P E_t \left(\frac{\lambda_{t+1}^E}{\lambda_t^E} q_{t+1}^k \psi^k \left(\frac{I_{t+1}}{I_t} - 1 \right) \left(\frac{I_{t+1}}{I_t} \right)^2 \right). \tag{14}$$

[1] Except for a shock to monetary policy, we assume that each disturbance follows a stochastic AR(1) process $a_t = (1-\rho_a)a + \rho_a a_{t-1} + \varepsilon_t^a$, where ρ_a is the autoregressive coefficient, a is the respective steady-state value and ε_t^a is i.i.d. process with zero mean and variance σ_a^2.

2.4. Retailers

Retailers operate in a monopolistically competitive market and face the quadratic adjustment cost parametrised by ψ^P that introduce the nominal rigidity into the model. Retailers choose the price of the product $p_t(j)$ to maximise

$$\max_{\{p_t(j)\}} E_0 \sum_{\tau=0}^{\infty} \Lambda_{0,t}^P \left[\left(\frac{p_t(j)}{p_t} - mc_t \right) y_t(j) - \frac{\psi^P}{2} \left(\frac{p_t(j)}{p_{t-1}(j)} - 1 \right)^2 y_t \right] \tag{15}$$

with respect to the demand coming from the intra-optimisation of the households

$$y_t(j) = \left(\frac{p_t(j)}{p_t} \right)^{-\epsilon_t} y_t \tag{16}$$

where p_t is the price level, $mc_t = 1/x_t$ are the real marginal costs defined as an inverse of mark-up on the wholesale goods and $\epsilon_t = mk_t^y/(mk_t^y - 1)$ is the stochastic demand price elasticity. The optimisation yields a New Keynesian Phillips curve

$$(1 - \epsilon_t) + \epsilon_t mc_t - \psi^P(\pi_t - 1)\pi_t + \beta_P \frac{\lambda_{t+1}^P}{\lambda_t^P} \psi^P (\pi_{t+1} - 1)\pi_{t+1} \frac{y_{t+1}}{y_t} = 0, \tag{17}$$

2.5. Banks

The banking sector is modelled according to Gambacorta and Signoretti (2014) who simplify the framework of Gerali et al. (2010).

The role of banks is to collect deposits from patient households, issue loans to impatient entrepreneurs, and accumulate own bank capital. Each bank needs to obey the balance sheet identity stating that loans are equal to deposits plus bank capital. The deposit market is assumed to be perfectly competitive while the loan market is characterised by monopolistic competition. Banks are assumed to be composed of two branches – a wholesale branch and a retail branch, and face quadratic adjustment costs (parametrised by θ) related to the capital-to-asset position K_t^b/B_t and its target parametrised by ν^b.

The wholesale branch collects deposits $D_t = d_t^P$ from patient households at the deposit interest rate that coincides with the policy rate r_t^{ib} and issues wholesale loans, $B_t = b_t^E$, at the wholesale loan rate R_t^b. The wholesale branch chooses the optimal level of deposits D_t and loans B_t to maximise

$$\max_{\{B_t, D_t\}} E_0 \sum_{t=0}^{\infty} \Lambda_{0,t}^P \Bigg[(1 + R_t^b) B_t - (1 + r_t^{ib}) D_t$$
$$- K_t^b - \frac{\theta}{2} \left(\frac{K_t^b}{B_t} - \nu^b \right)^2 K_t^b \Bigg] \tag{18}$$

subject to the balance sheet identity $B_t = D_t + K_t^b$. The first order condition returns the equation describing the relationship between the wholesale loan rate and the capital-to-asset position of the bank

$$R_t^b = r_t^{ib} - \theta \left(\frac{K_t^b}{B_t} - \nu^b \right) \left(\frac{K_t^b}{B_t} \right)^2. \tag{19}$$

The retail branch purchases wholesale loans from the wholesale branch, differentiates them at no cost and sells them to impatient entrepreneurs at the retail loan rate r_t^{bE}. In doing so, the retail branch fixes the retail loan rate by applying the markup, $\bar{\mu}^{bE}$, on the wholesale loan rate R_t^b. Therefore, the retail loan rate for impatient households r_t^{bE} is given by

$$r_t^{bE} = r_t^{ib} - \theta \left(\frac{K_t^b}{B_t} - \nu^b \right) \left(\frac{K_t^b}{B_t} \right)^2 + \bar{\mu}^{bE}. \tag{20}$$

Aggregate bank capital, K_t^b, evolves according to the standard law of motion

$$K_t^b = K_{t-1}^b (1 - \delta^b) + J_{t-1}^B \tag{21}$$

where δ^b is parameter describing the proportion of the bank capital used in banking activity and J_t^B are aggregate bank profits given by

$$J_t^B = r_t^{bE} B_t - r_t^{ib} D_t - \frac{\theta}{2} \left(\frac{K_t^b}{B_t} - \nu^b \right)^2 K_t^b. \tag{22}$$

Leverage is defined as the ratio of aggregate loans and bank capital

$$lev_t = \frac{B_t}{K_t^b}. \tag{23}$$

2.6. Monetary authority, equilibrium and other definitions

The central bank sets its policy rate according to the Taylor-type rule

$$(1 + r_t^{ib}) = (1 + r^{ib})^{(1-\rho^{ib})} (1 + r_{t-1}^{ib})^{\rho^{ib}} \left(\frac{\pi_t}{\pi} \right)^{\phi_\pi (1-\rho^{ib})} \varepsilon_t^r \tag{24}$$

where r_{ib} is the steady state of the policy rate, π the steady state of inflation, ρ_{ib} reflects monetary policy inertia, ϕ_π is the weight on inflation, and ε_t^r is a white noise monetary policy shock with variance σ_r^2.

The market clearing equations are

$$y_t = c_t + I_t + \delta^b K_{t-1}^b \tag{25}$$

with aggregate consumption $c_t = c_t^E + c_t^P$. The flow of funds is given by

$$c_t^E + q_t^k K_t + (1 + r_{t-1}^{bE}) b_{t-1}^E + w_t^P l_t^P = \frac{y_t}{x_t} + q_t^k (1 - \delta) K_{t-1} + b_t^E. \tag{26}$$

2.7. Occasionally binding constraint

A contribution of this paper is the inroduction of a non-linear feature into the model represented by occasionally binding credit constraint. Following Brzoza-Brzezina et al. (2015), the equality constraint described by equation (7) is replaced with smooth penalty function

$$\Psi_t^E = \frac{1}{\eta}\exp\{\eta\Gamma_t^E\} \tag{27}$$

where η defines the curvature of the penalty function[2] and $\Gamma_t^E = (1 + r_t^{bE})b_t^E - m^E q_{t+1}^k(1-\delta)K_t$. The derivative of the penalty function (27) with respect to b_t^E returns the penalty function slope

$$\Omega_t^E = (1 + r_t^{bE})\exp\{\eta\Gamma_t^E\}. \tag{28}$$

The penalty function (27) is introduced into the model as an additive component of the utility function of impatient entrepreneurs. Hence, the difference between the EBC model and the OBC model lies in the specification of the optimisation problem of this agent. Maximising (5) with respect to (6), taking into account (8) and (27), and combining the resulting first order conditions returns the new specifications of the entrepreneurs' consumption-Euler equation

$$\frac{1}{c_t^E} = \beta_E E_t\left(\frac{1 + r_t^{bE}}{c_{t+1}^E}\right) + \Omega_t^E \tag{29}$$

and the entrepreneurs' user cost of housing capital

$$\frac{q_t^k}{c_t^E} = E_t\left(\frac{\beta_E}{c_{t+1}^E}\left(\frac{\mu y_{t+1}}{K_t x_{t+1}} + q_{t+1}^k(1-\delta)\right) + m^E q_{t+1}^k(1-\delta)\exp\{\eta\Gamma_t^E\}\right). \tag{30}$$

3. Calibration and properties of the models

3.1. Calibration

We calibrate the model predominantly based on the values presented in Gambacorta and Signoretti (2014). The calibration of the parameters is summarised in Table 1.

The discount factor of households, β_P, is set calibrated to 0.996, which implies 2 % steady state of the policy rate. The discount factor of entrepreneurs, β_E, is set at 0.975 as in Iacoviello (2005), which ensures that entrepreneurs are less patient than households. Following Galí (2008), the inverse of the Frisch elasticity, ϕ, is equal to 1. The share of capital used in the production, μ is set at 0.2 while the deprecetion rate of physical capital δ is set at 0.05. The steady state of the demand price elasticity, $\bar{\epsilon}$ is equal to 6, which implies the state steady state value of the mark-up 1.2. The stickiness parameters, ψ^k and ψ^P are set at 5 and 26.85 respectively. Following

[2] Low values of η imply very relaxed conditions while for η going to infinity the constraint becomes eternally binding.

Christensen, Corrigan, Mendicino, and Nishiyama (2007), the LTV ratio of entrepreneurs is equal to 0.35. The calibration of the banking sector parameters follows Gerali et al. (2010). The target capital-to-asset ratio, ν^b, the parameter governing the cost for managing the bank's capital position, δ^b, and the parameter characterising the capital adjustment cost, θ, are equal to 0.09, 0.059 and 11 respectively. The mark-up on the inter-bank interest rate is set at 2 %. The degree of monetary policy inertia is equal to 0.77 and the weight put on inflation is set at 1.5.

We pay a special attention to the parameter η in the penalty function that characterisis the OBC model. The parameter η defines how much the collateral constraint is binding. In case that η approaches infinity, the collateral constraint becomes eternally binding and the OBC model has the same properties as the baseline EBC model. On contrary, for small values of η, the constraint is occasionally binding. We select the value of η to be equal to 50 following Brzoza-Brzezina et al. (2015). Such calibration ensures that the collateral constraint is moderately binding in the steady state. To be specific, under the OBC model, the steady state leverage ratio equals to 34.2 % which is 0.8 p.p. below the baseline LTV ratio. Shocks are calibrated outside the model and their values are based on Gerali et al. (2010).

Parameter	**Description**	**Value**
β_H	Discount factor of households	0.996
β_E	Discount factor of entrepreneurs	0.975
δ	Depreciation rate of physical capital stock	0.05
δ^b	Cost for managing the bank's capital position	0.059
η	Penalty function parameter	50
$\bar{\epsilon}$	Demand elasticity of substitution	6
θ	Bank capital adjustment cost parameter	11
ψ^k	Investment adjustment costs	5
ψ^P	Price adjustment costs parameter	28.65
μ	Share of capital used in the production	0.2
m^E	Steady state LTV of entrepreneurs	0.35
$\bar{\mu}^{bE}$	Markup on the policy interest rate	0.005
ν^b	Target capital-to-assets ratio	0.09
ϕ	Inverse of the Frisch elasticity of labour supply	1
ϕ_π	Weight put on inflation	1.5
ρ^{ib}	Monetary policy inertia	0.77
ρ_a	Autoregressive coefficient – technology shock	0.95
ρ_{mk}	Autoregressive coefficient – markup shock	0.5
ρ_m	Autoregressive coefficient – LTV shock	0.892
σ_a	Standard deviation – technology shock	0.006
σ_{mk}	Standard deviation – markup shock	0.063
σ_m	Standard deviation – LTV shock	0.007
σ_r	Standard deviation – monetary policy shock	0.002

Table 1: **Calibration.**

3.2. Properties of the EBC model

The following paragraphs describe and explain the basic dynamics of the model. Figure 1 presents three out of four shocks included in the model. We left the LTV shock for the explanation of the workings of the OBC.

An improvement in the production process is modelled as a positive one standard deviation technology shock which makes the production more efficient. More efficient production process leads to higher output and lower prices, and therefore to lower inflation. The interest rate on loans drops which resembles the reaction of the central bank to cut its policy rate to increase inflation. An investment activity rises with better technology and easier access to credit that is mirrored in a higher demand for loans and subsequent expansion in bank leverage. Asset prices increase, and consumption rises due to higher wages.

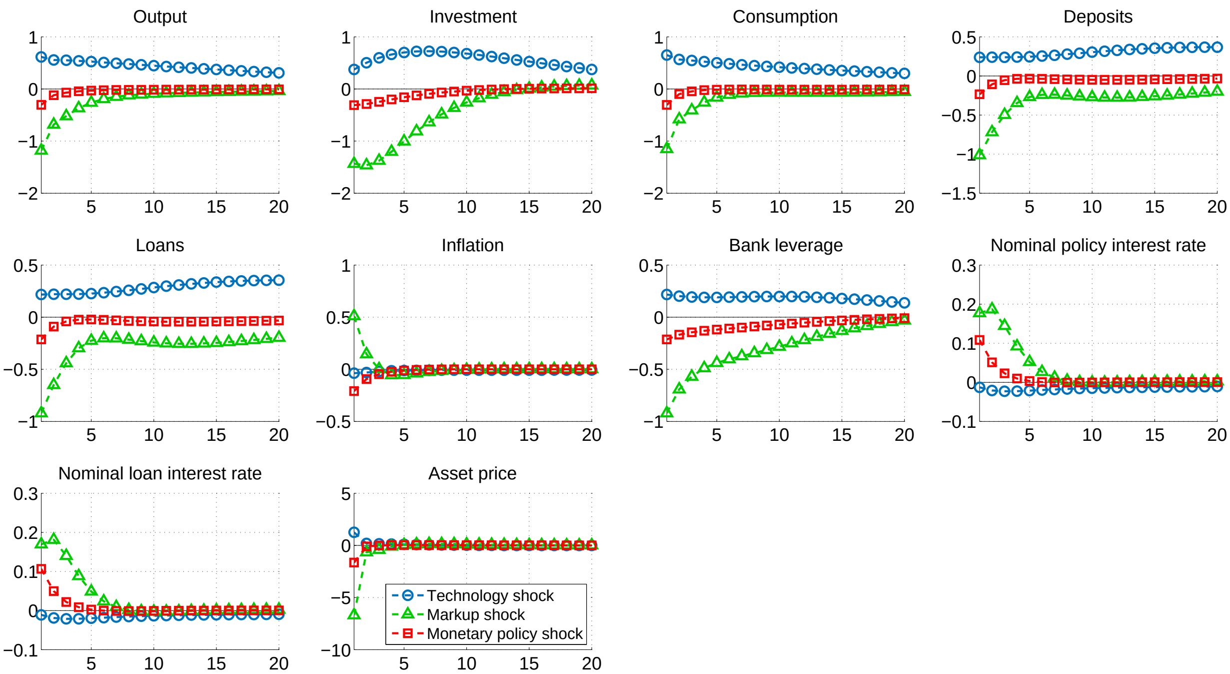


Figure 1. **Properties of the baseline EBC model.** The IRFs depict one standard deviation shocks. All variables except for interest rates are expressed as percentage deviations from steady state. Interest rates are expressed in absolute deviations.

A cost-push shock is modelled as an increase in the markup on goods. An adverse inflation shock causes output, investment and consumption to fall significantly. The central bank increases its policy interest rate to decrease inflation. The interest on loans follows the dynamics of the policy interest rate and rises as well. Financing conditions of the loans become adverse leading to a sharp contraction in loans and a decrease in bank leverage. Asset prices fall.

A contractionary monetary policy shock is represented by a one standard deviation shock in the policy interest rate. Output and inflation decrease on impact. A higher policy rate is reflected by the increase in the interest rate on loans. Decreasing price of assets together and the increasing interest rate on loans cause a decline in the value of the collateral resulting in a lower volume of loans. Deposits decrease more than loans to meet the balance sheet identity of the commercial banks.

3.3. Workings of the OBC

Before we proceed to the description of the workings of the OBC, we describe the dynamics of the EBC model under negative one standard deviation shock to the LTV ratio of entrepreneurs. The LTV shock can be perceived as a result of the behaviour of financial sector institutions which is a standard interpretation in the literature. As Figure 2 shows, after the negative shock to the LTV ratio, a contraction in loan demand appears due to tighter financing conditions which decrease entrepreneurs' net worth. Subsequently, investment activities fall due to subdued loan demand which translates into lower output and consumption accompanied by lower inflation. Deposits and bank leverage fall as well as asset prices. The central bank fights decreased inflation by cutting its policy interest rate.

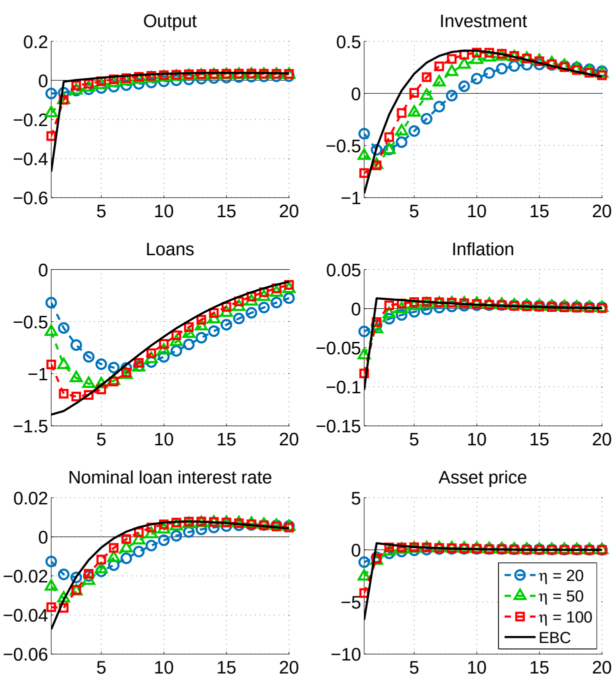


Figure 2. **Workings of the OBC.** The IRFs depict negative one standard deviation shock to the LTV ratio. All variables except for interest rates are expressed as percentage deviations from steady state. Interest rates are expressed in absolute deviations.

We further examine how the value of the OBC coefficient, η, affects the dynamics of the model. Figure 2 offers the dynamics of the model under three alternative calibrations of OBC and compares it with the EBC baseline setting. As it has been highlighted before, lower values of η imply more relaxed conditions. On the other hand, as η approaches infinity, the OBC constraint becomes binding and behaves as the EBC constraint. Therefore, the EBC model is a special case of the OBC model. As Figure 2 shows, the dynamics of the model under the OBC set-up is more moderate. The responses become hump-shaped in most cases and are smoother as well, which is something to be expected in real data. Compared to the EBC variant in which the strongest response usually comes on impact, the OBC displays more gradual reactions with the strongest impacts after several quarters.[3] As the OBC becomes less binding (i.e. η becomes lower and the penalty function becomes steeper), the responses are less pronounced.

3.4. Asymmetries under the OBC

As the data show, recessions are often more severe than expansions, and therefore, data exhibit asymmetries. However, under the EBC, the models are not able to replicate asymmetries in reactions of the macroeconomic variables, and the IRFs are symmetric under positive and negative shocks. This shortcoming of EBC models is something which is not expected to be present in reality and is not supported by data. The OBC framework, on the other hand, offers substantial flexibility and the construction of the penalty function should enable the asymmetric responses of the macroeconomic variables. Therefore, we devote this subsection to the examination of the OBC framework under both positive and negative shocks.

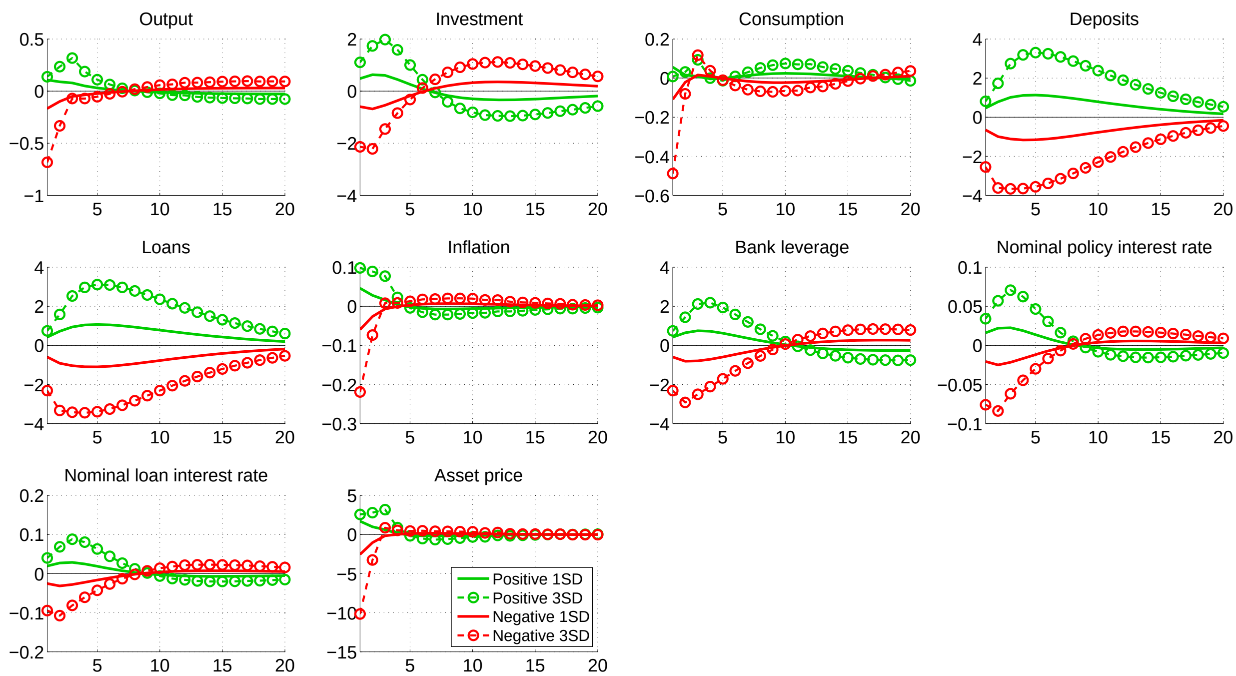


Figure 3. **Asymmetric property of the OBC.** The IRFs depict negative and positive shocks to the LTV ratio. All variables except for interest rates are expressed as percentage deviations from steady state. Interest rates are expressed in absolute deviations.

[3] For example Gilchrist and Zakrajšek (2012) identifies hump-shaped responses and inertia in reactions of macroeconomic variables to financial shocks.

Figure 3 shows the state-dependent responses of the main variables to small (one standard deviation) and large (three standard deviations) shocks to the LTV ratio. For one standard deviation shocks, the responses are symmetric. This result is not surprising since the penalty function is smooth. If we consider larger shocks, the model starts to display clear asymmetries in the responses to LTV easing and tightening. The difference resides not only in the size of the responses but also in their shapes. Compared to a moderate increase in loans in case of LTV easing, LTV tightening is followed by a more pronounced decline in loans. The negative impact on loans translates into a more significant decrease in consumption, output and investment. The impact on asset prices is also larger in case of the negative LTV shock compared to the positive one. The explanation behind these substantial asymmetries resides in the construction of the OBC. Since the LTV ratio is a direct component of the collateral constraint, the OBC can generate asymmetric behaviour of the responses in case of negative and positive shocks. The same will also hold for other shocks that substantially affect the variables in the collateral constraint.

As we have shown, the model with occasionally binding constraint proves to be more appropriate, since it has more plausible characteristics, such as hump-shaped and asymmetric responses.

4. Taylor-type rules and optimal weights

4.1. Taylor-type rules

We test the performance of several Taylor-type rules. We assume that the central bank implements the baseline rule which reacts only to inflation movements. The second rule adds to the baseline rule a measure of economic slack represented by output. The third alternative augments the baseline rule with financial variable - asset prices. Therefore, a general Taylor-type rule can be described by

$$(1+r_t^{ib}) = (1+r^{ib})^{(1-\rho^{ib})}(1+r_{t-1}^{ib})^{\rho^{ib}} \left(\left(\frac{\pi_t}{\pi}\right)^{\phi_\pi} \left(\frac{y_t}{y}\right)^{\phi_y} \left(\frac{q_t^k}{q^k}\right)^{\phi_q} \right)^{1-\rho^{ib}} \tag{31}$$

where ϕ_π, ϕ_y and ϕ_{q^k} are respective weights that are to be optimised. The optimisation procedures are described in the following subsection.

4.2. Methodology to measure macroeconomic benefits

We employ two distinct approaches to measure macroeconomic benefits and to find the optimal weights of the augmented Taylor-type rules. The first approach is a standard minimisation of *a quadratic loss function* based on the concept of the Taylor curves. We assume that the central bank minimises the weighted sum of variances of inflation and output

$$L_t = Var(\pi_t) + \alpha Var(y_t) \tag{32}$$

where Var is variance and α is the weight assigned to output and is allowed to vary within the interval $[0, 1]$. We assume that the primary goal of the central bank is to maintain stable inflation, and therefore, we assign the weight of the magnitude one to inflation in the loss function. For each value of α, we compute the optimal weights of the augmented Taylor-type rules' coefficients based on a grid-search method. The coefficients of the Taylor-type rules are restricted to intervals: $\phi^{\pi} \in (1, 3]$, $\phi^{y} \in [0, 1]$ and ϕ_q by increments of 0.1.

The second approach is based on *the maximisation of agents' welfare* in which we follow Gambacorta and Signoretti (2014). We compute agents' welfare using a second-order approximation of the utility functions of the agents in the economy. To find the optimal coefficients, we compute agents' welfare for each combination of the weights in the Taylor-type rule. Since there are two agents in the economy each with different discount factors, we work with two distinct welfare functions under given Taylor-type rule R. The welfare functions for households ($W^P_{0,R}$) and entrepreneurs ($W^E_{0,R}$) are described by

$$W^P_{0,R} = E_0 \sum_{t=0}^{\infty} \beta_P^t \left[\log(c_t^P) - \frac{(l_t^P)^{1+\phi}}{1+\phi} \right]. \tag{33}$$

$$W^E_{0,R} = E_0 \sum_{t=0}^{\infty} \beta_E^t \log(c_t^E). \tag{34}$$

Since the units of welfare have no direct interpretation, we employ consumption equivalent units, which is a common approach in the similar literature. The explanation of the consumption equivalent units is then how much of the steady-state share of consumption would make the agent under the augmented Taylor-type rule as well off as with the standard baseline rule. Based on the functional forms of the utility functions, the expressions for the consumption equivalents for both agents are

$$\lambda^P = 1 - \exp\{(W^P_{0,SR} - W^P_{0,AR})(1 - \beta^P)\}. \tag{35}$$

$$\lambda^E = 1 - \exp\{(W^E_{0,SR} - W^E_{0,AR})(1 - \beta^E)\}. \tag{36}$$

where $W^E_{0,SR}$ and $W^P_{0,SR}$ are welfares under the standard baseline rule, and $W^E_{0,AR}$ and $W^P_{0,AR}$ are welfares under the augmented rule.

4.3. Simulations under calibrated shocks

The results of the optimization routine based on the simple loss function are summarized in Tables 2, 3 and 4, while the optimisation based on agents' welfare is presented in Table 5. All mentioned tables also offer a comparison between the optimisations under the EBC and OBC models. For the sake of brevity, we do not present all the results for each value of α, and we omit few results within the interval $[0, 1]$.[4]

[4] The results for each value of α can be found in Appendix A.

Table 2 summarises the optimisation under one standard deviation positive technology shock. The augmented rule with asset prices delivers the best performance and outperforms the other two rules. On the contrary, the baseline rule reacting only to inflation delivers the worst outcomes. The only exception is a case when the central bank does not put any weight on the output stabilisation in its loss function. In this case, the best performance is achieved under the rule prescribing the highest possible weight on inflation. This particular result is in line with the "Jackson Hole consensus" and is common across the similar studies (e.g. Bernanke and Gertler (2001) or Schmitt-Grohé and Uribe (2007)). The gain of the augmented rule with asset prices increases with the higher value of the weight α. When comparing the optimised coefficients under the EBC and OBC settings, they are almost similar. For value $\alpha = 1$, gain achieved under the EBC setting is 11.88 % and 12.12 % under the OBC variant.

		Baseline rule		**Augmented rule – output**				**Augmented rule – asset prices**			
EBC	α	ϕ_π	L_t	ϕ_π	ϕ_y	L_t	**Gain**	ϕ_π	ϕ_q	L_t	**Gain**
	0	3	0.000	3	0	0.000	0.00 %	3	0	0.000	0.00 %
	0.1	1.2	0.005	1.2	0	0.005	0.00 %	3	0.5	0.005	2.27 %
	0.3	1.1	0.015	1.1	0	0.015	0.00 %	1.9	1	0.014	6.03 %
	0.5	1.1	0.026	1.1	0	0.026	0.00 %	1.1	1	0.023	8.82 %
	0.7	1.1	0.036	1.1	0.1	0.036	0.63 %	1.1	1	0.032	10.57 %
	0.9	1.1	0.046	1.1	0.1	0.045	1.09 %	1.1	1	0.041	11.54 %
	1	1.1	0.051	1.1	0.1	0.050	1.26 %	1.1	1	0.045	11.88 %
OBC											
	0	3	0.000	3	0	0.000	0.00 %	3	0	0.000	0.00 %
	0.1	1.2	0.005	1.2	0	0.005	0.00 %	3	0.5	0.005	1.49 %
	0.3	1.1	0.015	1.1	0	0.015	0.00 %	1.8	1	0.015	5.64 %
	0.5	1.1	0.026	1.1	0	0.026	0.00 %	1.1	1	0.023	8.83 %
	0.7	1.1	0.036	1.1	0.1	0.036	0.59 %	1.1	1	0.036	11.29 %
	0.9	1.1	0.046	1.1	0.1	0.046	1.05 %	1.1	1	0.041	11.75 %
	1	1.1	0.051	1.1	0.1	0.051	1.21 %	1.1	1	0.045	12.12 %

Table 2: **Optimised Taylor-type rules under loss function – positive technology shock.** Gain is a percentage difference between the loss achieved under the baseline and augmented rule.

The augmented rule with asset prices seems to deliver plausible outcomes under the markup shock. However, the results are not so convincing as in the case of the technology shock. As Table 3 shows, the results are substantially dependent on the chosen value of the weight α. When the central bank pays no or slight attention to variation in output, the best response regarding the minimum loss is achieved under the baseline rule. On the other hand, if the weight α reaches 0.5, the minimum loss is found under the rule augmented with asset prices. Again, the rule augmented with asset prices can deliver the best performance under the OBC variant in certain cases. However, the optimised coefficients are substantially different from those found under the EBC setting. For values of α exceeding 0.7, the optimisation under the EBC model delivers the coefficient on inflation ϕ_{pi} equal to 3 and a high reaction to asset prices development, whereas the optimised coefficient on inflation takes the lowest possible value accompanied by a slight reaction to asset prices for the

OBC model. Moreover, gain achieved under the OBC is not as high as in the EBC setting.

		Baseline rule		Augmented rule – output				Augmented rule – asset prices			
EBC	α	ϕ_π	L_t	ϕ_π	ϕ_y	L_t	**Gain**	ϕ_π	ϕ_q	L_t	**Gain**
	0	3	0.002	3	0	0.002	0.00 %	3	0	0.002	0.00 %
	0.1	3	0.006	3	0	0.006	0.00 %	3	0	0.006	0.00 %
	0.3	1.1	0.012	1.1	0	0.012	0.00 %	1.1	0	0.012	0.00 %
	0.5	1.1	0.017	1.1	0	0.017	0.00 %	1.2	0.1	0.016	3.54 %
	0.7	1.1	0.021	1.1	0.2	0.021	2.70 %	3	0.7	0.019	11.32 %
	0.9	1.1	0.026	1.1	0.4	0.024	6.77 %	3	0.9	0.021	19.29 %
	1	1.1	0.028	1.1	0.5	0.026	9.04 %	3	1	0.022	22.87 %
OBC											
	0	3	0.002	3	0	0.002	0.00 %	3	0	0.002	0.00 %
	0.1	3	0.006	3	0	0.006	0.00 %	3	0	0.006	0.00 %
	0.3	1.4	0.011	1.4	0	0.011	0.00 %	1.4	0	0.011	0.00 %
	0.5	1.1	0.015	1.1	0	0.015	0.00 %	1.1	0	0.015	0.00 %
	0.7	1.1	0.019	1.1	0.1	0.019	0.81 %	1.1	0.1	0.019	4.22 %
	0.9	1.1	0.023	1.1	0.2	0.023	3.09 %	1.1	0.2	0.021	9.65 %
	1	1.1	0.025	1.1	0.3	0.024	4.64 %	1.1	0.2	0.022	12.20 %

Table 3: **Optimised Taylor-type rules under loss function – positive markup shock.** Gain is a percentage difference between the loss achieved under the baseline and augmented rule.

The last investigated shock is a positive LTV shock. The results of the coefficient optimisation based on the minimisation of the loss function are summarised in Table 4. Unlike the previous cases, both augmented rules (with output and asset prices) deliver better performance than the baseline rule for all values of the weight α. Moreover, gains achieved under the augmented rules are the most apparent ones (gain achieves even 77 % for $\alpha = 1$). The lowest value of the loss function is found under the rule augmented with asset prices that suggests a strong response to inflation and a moderate response to asset prices. These conclusions hold for both EBC and OBC variant (even though there are slight differences).

Table 5 summarises the coefficients of the welfare-maximising rules along with the consumption equivalents. For the sake of brevity, we do not present the results of the rule augmented with output. We find that in the case of the EBC model, the augmented rule with asset prices makes the agents better off. The rule is welfare improving in all investigated shocks. These results go hand in hand with the results stemming from the optimisation of the loss function. For almost all shocks, the augmented rule with asset prices prescribes the highest possible value of the coefficient ϕ_q. This not, however, true for the OBC model. In this case, the rule performs as welfare improving only for households and brings no benefit for entrepreneurs at the same time (the coefficient on asset prices takes 0 value in all cases). This particular result suggests that when the constraint is occasionally binding, the role of financial frictions is relaxed and fluctuations in asset prices are not inefficient for entrepreneurs.

To conclude, this section provides evidence that reacting to financial developments might be beneficial for the central bank. Based on the achieved results, reacting to asset prices can help

		Baseline rule		Augmented rule – output				Augmented rule – asset prices			
EBC	α	ϕ_π	L_t	ϕ_π	ϕ_y	L_t	**Gain**	ϕ_π	ϕ_q	L_t	**Gain**
	0	3	0.000	3	0.5	0.000	37.27 %	3	0.1	0.000	77.22 %
	0.1	3	0.000	3	0.9	0.000	27.20 %	3	0.1	0.000	54.47 %
	0.3	3	0.001	3	1	0.000	29.62 %	3	0.2	0.000	59.71 %
	0.5	3	0.001	3	1	0.001	30.21 %	3	0.2	0.000	61.64 %
	0.7	3	0.002	3	1	0.001	30.47 %	3	0.2	0.001	62.52 %
	0.9	3	0.002	3	1	0.001	30.63 %	3	0.2	0.001	63.03 %
	1	3	0.002	3	1	0.001	30.68 %	3	0.3	0.002	63.31 %
OBC											
	0	3	0.000	3	0.4	0.000	45.60 %	3	0.1	0.000	74.35 %
	0.1	3	0.000	3	0.5	0.000	18.91 %	3	0.1	0.000	45.78 %
	0.3	3	0.000	3	0.7	0.000	15.09 %	3	0.1	0.000	39.90 %
	0.5	3	0.000	3	0.8	0.000	15.31 %	2	0.1	0.000	38.80 %
	0.7	3	0.000	3	1	0.000	16.22 %	1.6	0.1	0.000	38.73 %
	0.9	3	0.000	3	1	0.000	16.95 %	3	0.2	0.000	39.11 %
	1	3	0.000	3	1	0.000	17.21 %	3	0.2	0.000	39.98 %

Table 4: **Optimised Taylor-type rules under loss function – positive LTV shock.** Gain is a percentage difference between the loss achieved under the baseline and augmented rule.

	Households						**Entrepreneurs**					
	Baseline rule		**Augmented rule**				**Baseline rule**		**Augmented rule**			
EBC	ϕ_π	W_P	ϕ_π	ϕ_q	W_P	λ^P	ϕ_π	W_E	ϕ_π	ϕ_q	W_E	λ^E
Technology	1.1	-118.63	3	0.7	-118.62	0.00 %	1.1	-123.81	1.9	1	-123.80	0.01 %
Markup	1.1	-118.31	1.1	1	-117.79	0.21 %	1.1	-123.09	1.1	1	-122.37	1.79 %
LTV	3	-118.83	1.1	1	-118.67	0.06 %	3	-124.07	1.1	1	-123.86	0.53 %
OBC												
Technology	1.1	-118.72	1.1	1	-118.71	0.00 %	3	-123.61	3	0	-123.61	0.00 %
Markup	1.1	-118.43	1.1	1	-117.87	0.22 %	3	-121.67	3	0	-121.67	0.00 %
LTV	3	-118.98	1.1	1	-118.77	0.01 %	1.1	-122.94	1.1	0	-122.94	0.00 %

Table 5: **Optimised Taylor-type rules under welfare maximisation – calibrated shocks.** The first column indicates the type of a shock. The augmented rule represents the rule with asset prices.

to stabilise volatility of inflation and output, and can also increase welfare of economic agents. The optimal reactions are, however, shock- and model-dependent. Moreover, a chosen specification of the loss function plays a crucial role. An explanation behind why the rule with asset prices delivers the best performance in most cases might be that, in the model outlined in this paper, asset prices significantly affect marginal costs of production through the return to capital and investment activities, and therefore, are closely linked to inflation.

5. Robustness check

5.1. Are macroeconomic gains of the augmented rule with asset prices higher under larger shocks?

In this section we demonstrate, whether the positive implications of the augmented rule with asset prices prevail even under larger shocks with higher persistence. We enlarge the shocks to 3 standard deviations and increase the autoregressive coefficients to $\rho_a = 0.98$, $\rho_m = 0.95$ and $\rho_{mk} = 0.75$. We repeat the same optimisation procedures as in the previous subsection. The results of the optimisations under large technology, markup and LTV shocks are summarised in Tables 6, 7 and 8 respectively.

		Baseline rule		**Augmented rule – output**				**Augmented rule – asset prices**			
EBC	α	ϕ_π	L_t	ϕ_π	ϕ_y	L_t	**Gain**	ϕ_π	ϕ_q	L_t	**Gain**
	0	3	0.000	3	0	0.000	0.00 %	3	0	0.000	0.00 %
	0.1	1.1	0.126	1.1	0	0.126	0.00 %	3	0.8	0.124	1.71 %
	0.3	1.1	0.378	1.1	0	0.378	0.00 %	1.2	1	0.363	3.73 %
	0.5	1.1	0.629	1.1	0	0.629	0.00 %	1.1	1	0.598	4.89 %
	0.7	1.1	0.881	1.9	0.1	0.879	0.14 %	1.1	1	0.833	5.39 %
	0.9	1.1	1.132	1.5	0.1	1.129	0.28 %	1.1	1	1.068	5.67 %
	1	1.1	1.258	1.3	0.1	1.253	0.36 %	1.1	1	1.185	5.76 %
OBC											
	0	3	0.000	3	0	0.000	0.00 %	3	0	0.000	0.00 %
	0.1	1.1	0.126	1.1	0	0.126	0.00 %	3	0.7	0.125	1.42 %
	0.3	1.1	0.378	1.1	0	0.378	0.00 %	1.2	1	0.364	3.71 %
	0.5	1.1	0.63	1.1	0	0.63	0.00 %	1.1	1	0.599	4.96 %
	0.7	1.1	0.833	1.8	0.1	0.882	0.11 %	1.1	1	0.834	5.50 %
	0.9	1.1	1.135	1.5	0.1	1.132	0.26 %	1.1	1	1.069	5.80 %
	1	1.1	1.261	1.3	0.1	1.256	0.33 %	1.1	1	1.186	5.91 %

Table 6: **Optimised Taylor-type rules under loss function – large technology shock.** The augmented rule represents the rule with asset prices. Gain is a percentage difference between the loss achieved under the baseline and augmented rule.

As Table 6 suggests, the augmented rule with asset prices still delivers the best performance out of three alternatives in the majority of cases. Both models (EBC and OBC) prescribe merely the same coefficients for different values of the weight α. Again, the rule augmented with output achieves better results than the baseline rule only after passing a certain threshold of the value

		Baseline rule		Augmented rule – output				Augmented rule – asset prices			
EBC	α	ϕ_π	L_t	ϕ_π	ϕ_y	L_t	**Gain**	ϕ_π	ϕ_q	L_t	**Gain**
	0	3	0.010	3	0	0.010	0.00 %	3	0	0.010	0.00 %
	0.1	2.3	0.099	2.3	0	0.099	0.00 %	2.3	0	0.099	0.00 %
	0.3	1.1	0.243	1.1	0	0.243	0.00 %	3	0.3	0.231	4.94 %
	0.5	1.1	0.381	1.1	0.1	0.375	1.38 %	3	0.5	0.325	14.68 %
	0.7	1.1	0.518	1.1	0.2	0.495	4.49 %	3	0.8	0.397	23.32 %
	0.9	1.1	0.655	1.1	0.4	0.602	8.14 %	3	1	0.457	30.22 %
	1	1.1	0.724	1.1	0.4	0.651	10.09 %	2.8	1	0.485	33.01 %
OBC											
	0	3	0.013	3	0	0.013	0.00 %	3	0	0.013	0.00 %
	0.1	2.8	0.096	2.8	0	0.096	0.00 %	2.8	0	0.096	0.00 %
	0.3	1.1	0.233	1.1	0	0.233	0.00 %	1.1	0	0.233	0.00 %
	0.5	1.1	0.359	1.1	0.1	0.358	0.37 %	1.1	0.1	0.338	5.84 %
	0.7	1.1	0.486	1.1	0.2	0.474	2.50 %	1.1	0.2	0.423	12.95 %
	0.9	1.1	0.612	1.1	0.3	0.580	5.24 %	1.1	0.3	0.493	19.55 %
	1	1.1	0.676	1.1	0.3	0.631	6.68 %	1.1	0.4	0.524	22.51 %

Table 7: **Optimised Taylor-type rules under loss function – large mark-up shock.** The augmented rule represents the rule with asset prices. Gain is a percentage difference between the loss achieved under the baseline and augmented rule.

α. Compared to the calibrated shock, the augmented rules are still beneficial. However, gains are lower. For the markup shock, the EBC and OBC models return higher gains compared to the calibrated shock. Again, the rule augmented with asset prices outperforms the rule with output. However, both rules deliver worse results than the baseline rule for lower values of the weight α. There are also significant differences in the value of optimised coefficients in case of the rule with asset prices. The EBC model prescribes rather strong responses both to inflation and asset prices developments. On the other hand, the coefficients on inflation and asset prices are rather low under the OBC model. The optimisation under the large LTV shock is presented in table 8. Compared to the calibrated shock, the results are relatively the same. High values of gains characterise both augmented rules. The optimised coefficients under the EBC and OBC models are similar. However, the coefficient on inflation is not stable in case of the OBC model.

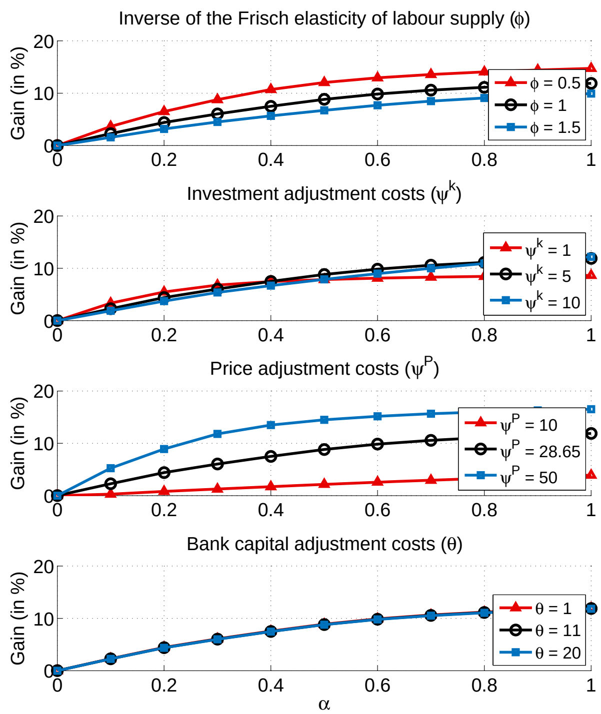
In Table 9, we also present the welfare-optimising rules with the respective consumption equivalents. Looking at the results related to the EBC model, the optimised coefficients are very close to their counterparts under the calibrated shocks. The augmented rule with asset prices is welfare enhancing for households and entrepreneurs as well. Moreover, resulting gains are higher compared to the optimisation under the calibrated shocks. The most apparent is the markup shock, where the consumption equivalent of entrepreneurs reaches almost 30 %. The comparison between the calibrated and the large shocks under the OBC model reveals that the results are almost identical. Again, the rule with asset prices is beneficial only for households with higher consumption equivalents compared to the calibrated shocks. On the other, it does not appear to be welfare-improving for entrepreneurs.

EBC	α	Baseline rule ϕ_π	L_t	Augmented rule – output ϕ_π	ϕ_y	L_t	Gain	Augmented rule – asset prices ϕ_π	ϕ_q	L_t	Gain
	0	3	0.001	3	0.6	0.000	39.93 %	3	0.1	0.000	71.86 %
	0.1	3	0.003	3	1	0.002	30.48 %	3	0.1	0.001	57.18 %
	0.3	3	0.007	3	1	0.005	31.99 %	3	0.2	0.003	62.38 %
	0.5	3	0.011	3	1	0.008	32.36 %	3	0.2	0.004	66.21 %
	0.7	3	0.016	3	1	0.010	32.54 %	3	0.2	0.005	67.95 %
	0.9	3	0.020	3	1	0.013	32.64 %	3	0.2	0.006	68.95 %
	1	3	0.022	3	1	0.015	32.67 %	3	0.2	0.007	69.30 %
OBC											
	0	3	0.000	3	0.3	0.000	45.74 %	3	0.1	0.000	50.63 %
	0.1	3	0.001	3	0.4	0.001	16.72 %	3	0.1	0.000	43.29 %
	0.3	3	0.002	3	0.7	0.001	14.03 %	2.4	0.1	0.001	42.28 %
	0.5	3	0.003	3	0.9	0.002	14.87 %	1.5	0.1	0.002	43.63 %
	0.7	3	0.004	3	1	0.003	16.21 %	1.2	0.1	0.002	45.24 %
	0.9	3	0.005	3	1	0.004	17.15 %	3	0.2	0.002	47.94 %
	1	3	0.005	3	1	0.004	17.48 %	3	0.2	0.003	49.11 %

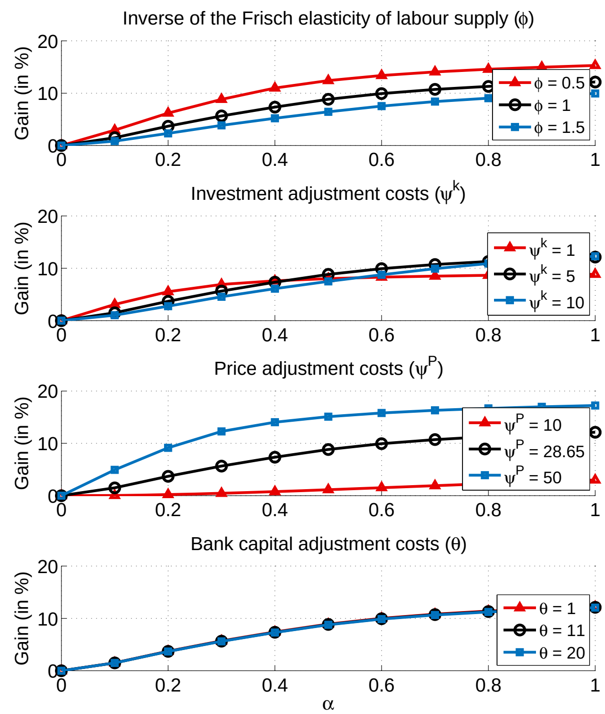
Table 8: **Optimised Taylor-type rules under loss function – large LTV shock.** The augmented rule represents the rule with asset prices. Gain is a percentage difference between the loss achieved under the baseline and augmented rule.

	Households						Entrepreneurs					
	Baseline rule		Augmented rule				Baseline rule		Augmented rule			
EBC	ϕ_π	W_P	ϕ_π	ϕ_q	W_P	λ^P	ϕ_π	W_E	ϕ_π	ϕ_q	W_E	λ^E
Technology	1.1	-119.97	3	0.8	-119.94	0.01 %	1.1	-124.03	2	1	-123.98	0.00 %
Markup	1.1	-119.99	1.1	1	-109.14	4.10 %	1.1	-121.03	1.1	1	-107.16	29.2 %
LTV	3	-120.77	1.1	1	-119.08	0.67 %	3	-126.81	1.1	1	-124.42	5.80 %
OBC												
Technology	1.1	-120.05	1.1	1	-119.99	0.02 %	3	-123.55	3	0	-123.55	0.00 %
Markup	1.1	-122.53	1.1	1	-110.41	4.73 %	3	-96.98	3	0	-96.98	0.00 %
LTV	3	-122.21	1.1	1	-119.91	0.91 %	1.1	-116.34	1.1	0	-116.34	0.00 %

Table 9: **Optimised Taylor-type rules under welfare maximisation – large shocks.** The first column indicates the type of a shock. The augmented rule represents the rule with asset prices.



(a) EBC model



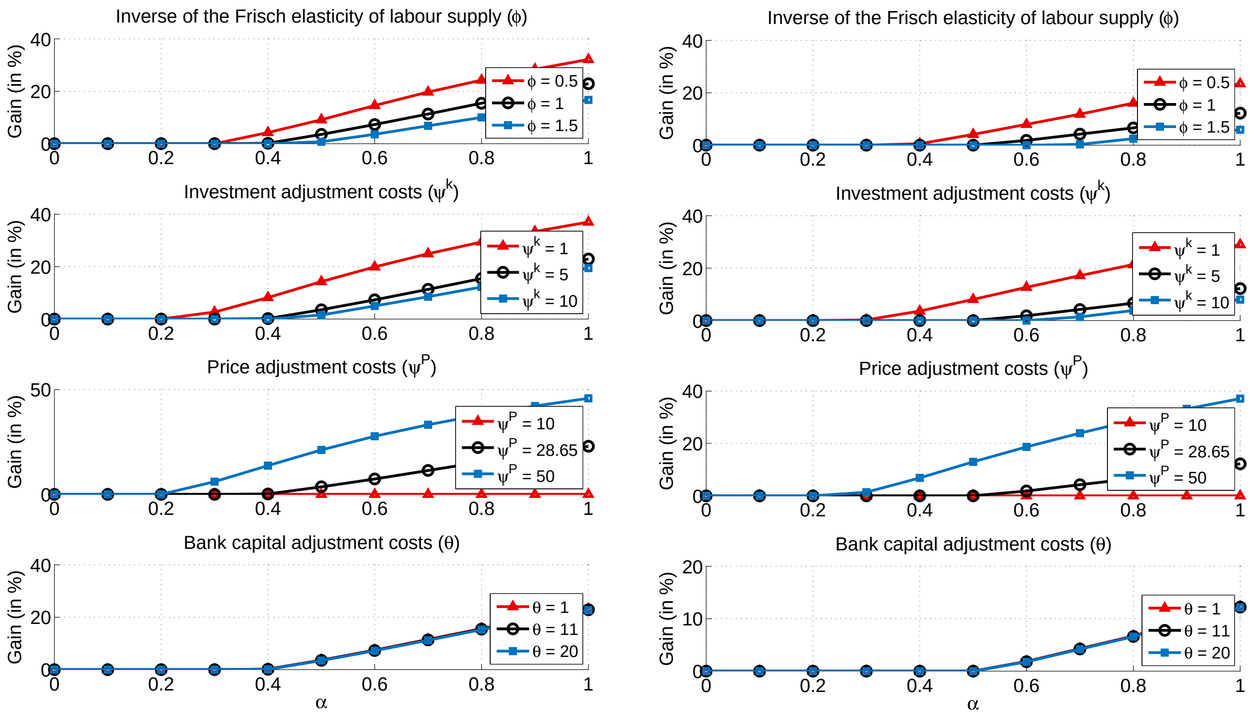
(b) OBC model

Figure 4. **Robustness check – technology shock.** Gain is a percentage difference between the loss achieved under the baseline rule and the rule augmented with asset prices. Gain is computed based on the optimised coefficients of the rules for each value of the weight α.

Overall, the conclusions made under the calibrated shocks still hold. However, gains of the augmented rules under the simple loss function are relatively smaller in case of the technology shock compared to the calibrated shocks. On the other hand, gains under the other two shocks are higher. The maximisation of welfare reveals that the rule with asset prices under the EBC model is welfare-improving with higher consumption equivalents for both agents, while it is welfare-improving only for households under the OBC model.

5.2. Sensitivity of the results to changes in the parameters

The following analysis highlights to what extent does the initial calibration of the model affects the results presented in the previous subsections. To investigate the sensitivity of the model to changes in the key parameters, we re-run the optimisation procedure based on the central bank's loss function for the baseline rule and the rule augmented with asset prices, and then we compute gain for each value of the weight α. The set of parameters included in the analysis comprises the parameters characterising the rigidity in the model – bank capital adjustment costs (θ), the inverse of the Frisch elasticity of labour supply (ϕ), investment adjustment costs (ψ^k) and the price stickiness ψ^P. The results of the sensitivity analysis are presented in Figures 4, 5 and 6. Each Figure consists of two subfigures describing the results under the EBC and the OBC model.

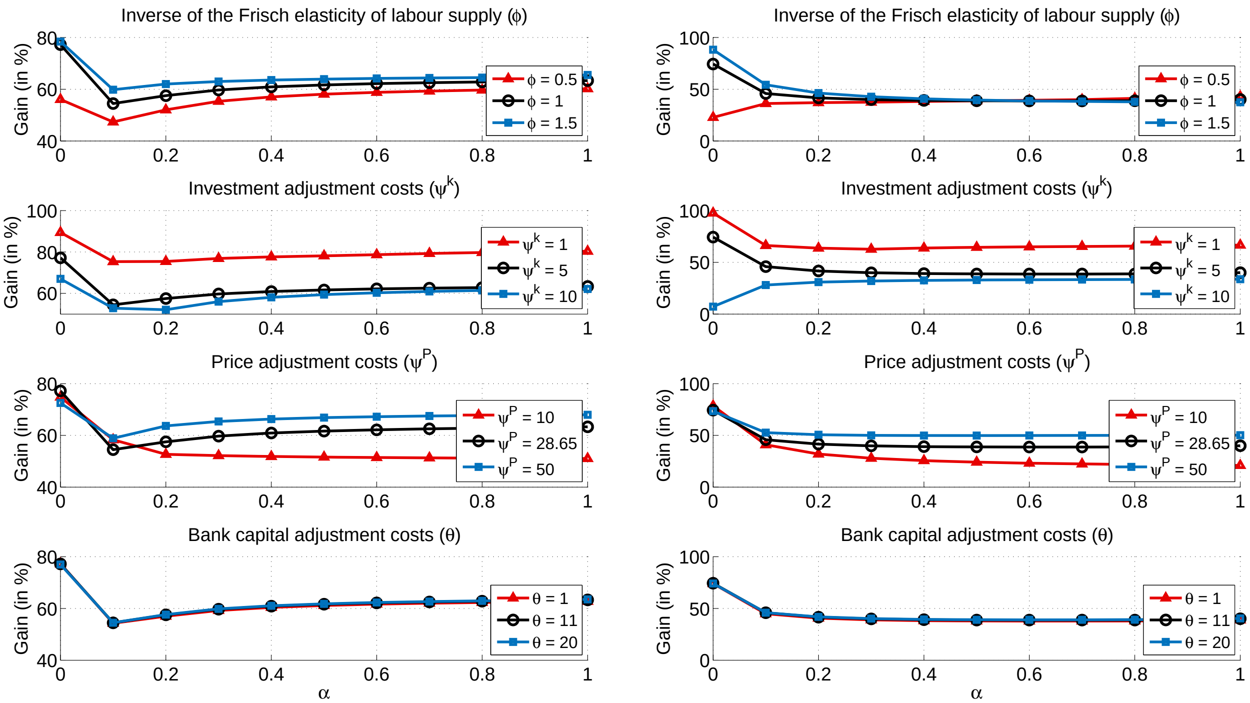


(a) EBC model (b) OBC model

Figure 5. **Robustness check – mark-up shock.** Gain is a percentage difference between the loss achieved under the baseline rule and the rule augmented with asset prices. Gain is computed based on the optimised coefficients of the rules for each value of the weight α.

As all Figures suggest, gains are both qualitatively and quantitatively merely the same in case of the EBC and the OBC model. The only exception seems to be the mark-up shock where gain from the augmented rule with asset prices starts to materialise with a higher value of the weight in the loss function α. Overall, the analysis shows that the results presented in this paper are robust to changes in the values of the key parameters of the model.

Looking closely at individual sensitivities reveals that the bank capital adjustments costs parameter θ causes almost none distortion. This result is not surprising since θ appears in the model in a multiplicative form together with the parameter ν^b being a decimal number (more precisely, the model includes a product $\theta\nu^3$. Since this product takes a very small number, the slope of the loan supply is almost unaffected, and therefore, gain is stable across different specifications of the value of the parameter θ. On the other hand, the most quantitative differences are caused by the investment adjustment costs parameter ψ^k and the price adjustment costs parameter ψ^P. The analysis shows that gain of the augmented rule tends to be higher for higher values of ψ^k and psi^P. The differences in gain achieved under the low and the high values of psi^P and ψ^k can be higher even more than 10 p.p. The last inspected parameter, the inverse of the Frisch elasticity of labour supply (ϕ), delivers similar results under different calibrations and does not affect the dynamics of the model considerably.



(a) EBC model (b) OBC model

Figure 6. **Robustness check – LTV shock.** Gain is a percentage difference between the loss achieved under the baseline rule and the rule augmented with asset prices. Gain is computed based on the optimised coefficients of the rules for each value of the weight α.

6. Conclusion

The augmented Taylor rules have been a subject of research for several decades. The recent financial crisis of 2008 has shown that the interconnection between the real and the financial side of an economy is considerable. Therefore, the performance of various financial variables in the Taylor rule started to be discussed. Moreover, the recent work in DSGE modelling shows that non-linearities play a crucial role, and therefore, the models should reflect this characteristic. The contribution of this research paper resides in comparison of the recently discussed Taylor-type rule augmented with asset prices with the rules accounting for changes in output in a closed economy model with occasionally binding constraint.

This exercise employs the closed economy model with occasionally binding constraint introduced via a penalty function approach. Three Taylor-type rules are investigated. The baseline rule is the one reacting to the developments in inflation. Then, two versions of the augmented rules are introduced – with output and asset prices. The coefficients of each rule are optimised based on the simple central banks' loss function using the grid-search method. Moreover, we perform the maximisation of the agents' welfare. We also test different specifications of the loss function by assigning different weights to its components. The achieved results are then a subject to a robustness check of the parameters of the model.

The main results of this paper are following. First, the model with occasionally binding constraint has more favourable properties regarding the hump-shaped and asymmetric impulse responses compared to the eternally binding constraint model. Second, the best rule in terms of the lowest value of the central banks' loss function proves to be the rule augmented with asset prices which outperforms both the rule with inflation and the rule augmented with output. The optimal reactions are, however, shock- and model-dependent. Moreover, a chosen specification of the loss function plays a crucial role. Third, the welfare maximisation reveals that reacting to asset prices might not be welfare-improving for both types of economic agents – households and entrepreneurs. This result is, however, model dependent. Fourth, the results are stable across different calibration of the key parameters of the model.

Appendix A. Figures and tables

		Baseline rule		Augmented rule – output				Augmented rule – asset prices			
EBC	α	ϕ_π	L_t	ϕ_π	ϕ_y	L_t	**Gain**	ϕ_π	ϕ_q	L_t	**Gain**
	0	3	0.000	3	0	0.000	0.00 %	3	0	0.000	0.00 %
	0.1	1.2	0.005	1.2	0	0.005	0.00 %	3	0.5	0.005	2.27 %
	0.2	1.1	0.010	1.1	0	0.010	0.00 %	3	1	0.010	4.39 %
	0.3	1.1	0.015	1.1	0	0.015	0.00 %	1.9	1	0.014	6.03 %
	0.4	1.1	0.020	1.1	0	0.020	0.00 %	1.4	1	0.019	7.50 %
	0.5	1.1	0.026	1.1	0	0.026	0.00 %	1.1	1	0.023	8.82 %
	0.6	1.1	0.031	1.1	0.1	0.031	0.29 %	1.1	1	0.028	9.84 %
	0.7	1.1	0.036	1.1	0.1	0.036	0.63 %	1.1	1	0.032	10.57 %
	0.8	1.1	0.041	1.1	0.1	0.041	0.89 %	1.1	1	0.036	11.12 %
	0.9	1.1	0.046	1.1	0.1	0.045	1.09 %	1.1	1	0.041	11.54 %
	1	1.1	0.051	1.1	0.1	0.050	1.26 %	1.1	1	0.045	11.88 %
OBC											
	0	3	0.000	3	0	0.000	0.00 %	3	0	0.000	0.00 %
	0.1	1.2	0.005	1.2	0	0.005	0.00 %	3	0.5	0.005	1.49 %
	0.2	1.1	0.010	1.1	0	0.010	0.00 %	2.9	1	0.010	3.69 %
	0.3	1.1	0.015	1.1	0	0.015	0.00 %	1.8	1	0.015	5.64 %
	0.4	1.1	0.021	1.1	0	0.021	0.00 %	1.3	1	0.019	7.34 %
	0.5	1.1	0.026	1.1	0	0.026	0.00 %	1.1	1	0.023	8.83 %
	0.6	1.1	0.031	1.1	0.1	0.031	0.25 %	1.1	1	0.028	9.92 %
	0.7	1.1	0.036	1.1	0.1	0.036	0.59 %	1.1	1	0.032	10.70 %
	0.8	1.1	0.041	1.1	0.1	0.041	0.85 %	1.1	1	0.036	11.29 %
	0.9	1.1	0.046	1.1	0.1	0.046	1.05 %	1.1	1	0.041	11.75 %
	1.0	1.1	0.051	1.1	0.1	0.051	1.21 %	1.1	1	0.045	12.12 %

Table 10: **Optimised Taylor-type rules under loss function – positive technology shock.** Gain is a percentage difference between the loss achieved under the baseline and augmented rule.

		Baseline rule		Augmented rule – output				Augmented rule – asset prices			
EBC	α	ϕ_π	L_t	ϕ_π	ϕ_y	L_t	**Gain**	ϕ_π	ϕ_q	L_t	**Gain**
	0	3	0.002	3	0	0.002	0.00 %	3	0	0.002	0.00 %
	0.1	3	0.006	3	0	0.006	0.00 %	3	0	0.006	0.00 %
	0.2	1.7	0.009	1.7	0	0.009	0.00 %	1.7	0	0.009	0.00 %
	0.3	1.1	0.012	1.1	0	0.012	0.00 %	1.1	0	0.012	0.00 %
	0.4	1.1	0.014	1.1	0	0.014	0.00 %	1.5	0.1	0.014	0.15 %
	0.5	1.1	0.017	1.1	0	0.017	0.00 %	1.2	0.1	0.016	3.54 %
	0.6	1.1	0.019	1.1	0.1	0.019	1.10 %	1.1	0.1	0.018	7.29 %
	0.7	1.1	0.021	1.1	0.2	0.021	2.70 %	3	0.7	0.019	11.32 %
	0.8	1.1	0.024	1.1	0.3	0.022	4.63 %	3	0.8	0.020	15.43 %
	0.9	1.1	0.026	1.1	0.4	0.024	6.77 %	3	0.9	0.021	19.29 %
	1	1.1	0.028	1.1	0.5	0.026	9.04 %	3	1	0.022	22.87 %
OBC											
	0	3	0.002	3	0	0.002	0.00 %	3	0	0.002	0.00 %
	0.1	3	0.006	3	0	0.006	0.00 %	3	0	0.006	0.00 %
	0.2	2.2	0.009	2.2	0	0.009	0.00 %	2.2	0	0.009	0.00 %
	0.3	1.4	0.011	1.4	0	0.011	0.00 %	1.4	0	0.011	0.00 %
	0.4	1.1	0.014	1.1	0	0.014	0.00 %	1.1	0	0.014	0.00 %
	0.5	1.1	0.015	1.1	0	0.015	0.00 %	1.1	0	0.015	0.00 %
	0.6	1.1	0.017	1.1	0	0.017	0.00 %	1.1	0.1	0.017	1.80 %
	0.7	1.1	0.019	1.1	0.1	0.019	0.81 %	1.1	0.1	0.019	4.22 %
	0.8	1.1	0.021	1.1	0.2	0.021	1.80 %	1.1	0.2	0.020	6.62 %
	0.9	1.1	0.023	1.1	0.2	0.023	3.09 %	1.1	0.2	0.021	9.65 %
	1.0	1.1	0.025	1.1	0.3	0.024	4.64 %	1.1	0.2	0.022	12.20 %

Table 11: **Optimised Taylor-type rules under loss function – positive markup shock.** Gain is a percentage difference between the loss achieved under the baseline and augmented rule.

		Baseline rule		Augmented rule – output				Augmented rule – asset prices			
EBC	α	ϕ_π	L_t	ϕ_π	ϕ_y	L_t	**Gain**	ϕ_π	ϕ_q	L_t	**Gain**
	0	3	0.000	3	0.5	0.000	37.27 %	3	0.1	0.000	77.22 %
	0.1	3	0.000	3	0.9	0.000	27.20 %	3	0.1	0.000	54.47 %
	0.2	3	0.000	3	1	0.000	28.95 %	3	0.2	0.000	57.51 %
	0.3	3	0.001	3	1	0.000	29.62 %	3	0.2	0.000	59.71 %
	0.4	3	0.001	3	1	0.001	29.98 %	3	0.2	0.000	60.90 %
	0.5	3	0.001	3	1	0.001	30.21 %	3	0.2	0.000	61.64 %
	0.6	3	0.001	3	1	0.001	30.36 %	3	0.2	0.000	62.15 %
	0.7	3	0.002	3	1	0.001	30.47 %	3	0.2	0.001	62.52 %
	0.8	3	0.002	3	1	0.001	30.56 %	3	0.2	0.001	62.80 %
	0.9	3	0.002	3	1	0.001	30.63 %	3	0.2	0.001	63.03 %
	1	3	0.002	3	1	0.001	30.68 %	3	0.3	0.002	63.31 %
OBC											
	0	3	0.002	3	0	0.002	0.00 %	3	0	0.002	0.00 %
	0.1	3	0.006	3	0	0.006	0.00 %	3	0	0.006	0.00 %
	0.2	2.2	0.009	2.2	0	0.009	0.00 %	2.2	0	0.009	0.00 %
	0.3	1.4	0.011	1.4	0	0.011	0.00 %	1.4	0	0.011	0.00 %
	0.4	1.1	0.014	1.1	0	0.014	0.00 %	1.1	0	0.014	0.00 %
	0.5	1.1	0.015	1.1	0	0.015	0.00 %	1.1	0	0.015	0.00 %
	0.6	1.1	0.017	1.1	0	0.017	0.00 %	1.1	0.1	0.017	1.80 %
	0.7	1.1	0.019	1.1	0.1	0.019	0.81 %	1.1	0.1	0.019	4.22 %
	0.8	1.1	0.021	1.1	0.2	0.021	1.80 %	1.1	0.2	0.020	6.62 %
	0.9	1.1	0.023	1.1	0.2	0.023	3.09 %	1.1	0.2	0.021	9.65 %
	1.0	1.1	0.025	1.1	0.3	0.024	4.64 %	1.1	0.2	0.022	12.20 %

Table 12: **Optimised Taylor-type rules under loss function – positive LTV shock.** Gain is a percentage difference between the loss achieved under the baseline and augmented rule.

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