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Optimal monetary policy rules and house prices: the role of financial frictions

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Abstract

We consider the scope for targeting house prices in simple monetary policy rules using a New Keynesian Dynamic Stochastic General Equilibrium model of the euro area with a housing sector and financial frictions on the household side. If the central bank's main objective is the minimization of inflation and output fluctuations, then a systematic response to house prices does not entail any systematic sizeable welfare improvement. When the objective of monetary policy is the maximization of aggregate (and individual) welfare, then the optimized rule does feature a systematic reaction to house price variations. The sign and size of such reaction crucially depend on the degree of financial frictions in the economy. If the economy is characterized by both a large share of constrained agents and a high average loan-to-value ratio, then it is optimal to positively react to house price movements. Finally, we show that uncertainty about the actual degree of financial frictions suggests some caution in the construction of optimal monetary policy rules. The welfare costs generated by systematically counteracting house price movements are in general smaller than those implied by a procyclical response.

JEL classification: E20; E44; E52.

Keywords: Optimal simple interest rate rules; Housing; Credit frictions.

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1 Introduction

For a number of years, consensus has been unanimous that no major useful role can be played by asset prices in monetary policy-making (see, e.g., Bernanke and Gertler (2001) and Mishkin (2007)). Asset prices' fate as a possible ingredient of monetary policy has long seemed set and sealed. The events of the last few years - with repeated crises accompanied by and often stemming from violent swings in asset prices - have stimulated the economic profession to reconsider whether asset prices should not play some role of sort in monetary policy-making after all. Asset booms and busts have been a systematic feature of the world economy for a number of decades now. However, never before the financial crisis that started in 2007 had their contribution to an economic downturn been so sharp, sizeable and extended as it was between 2008 and 2009. Those dramatic events have left many wondering whether there might not be good reasons why central banks should actually respond to asset prices.

In this paper we investigate whether the effectiveness of monetary policy may be enhanced by the inclusion of house prices among the objectives and/or the instruments of the central bank, exploring a variety of avenues. To this end, we develop a New Keynesian Dynamic Stochastic General Equilibrium (DSGE) model of the euro area which includes a housing sector and credit frictions on the household side. The model features a collateral constraint on a fraction of households, along the lines of Kiyotaki and Moore (1997) and Iacoviello (2005), along with both nominal and real rigidities, to replicate the observed dynamics of macroeconomic variables.[1] We restrict our attention to a class of simple monetary policy rules. More precisely, we analyse the behavior of the model economy in response to various types of exogenous shocks (which may or may not originate in the housing sector) and compute the optimal monetary policy rule according to different objective functions. Our aim is to characterize the response of monetary policy to house price fluctuations in a simple rule, depending on some fundamental properties of the economy such as the degree of nominal rigidities and the importance of financial frictions.

We first consider a central bank concerned with business cycle stabilization, i.e. the minimization of a weighted average of consumer price inflation and output fluctuations. Our results

[1]Recent contributions that introduce a housing sector in DSGE models for monetary policy analysis include among others Andrés, Arce, and Thomas (2011), Aspachs-Bracons and Rabanal (2011), Darracq Pariès and Notarpietro (2008), Forlati and Lambertini (2011), Finocchiaro and Queijo von Heideken (2012), Jeske and Liu (2012), Iacoviello and Neri (2010), Monacelli (2009) and Rubio (2011).

indicate, consistent with previous contributions in the literature, that adding the dynamics of house prices to a standard Taylor-type rule does not significantly move the optimal frontier, if at all.

We then consider the case in which a measure of house prices is included among the arguments of the monetary policymaker's objective function and ask the following question: does the policy rule so obtained deliver any sizeable improvement in consumers' welfare, compared to the case in which no attention is paid to house prices at all? We find that including an indicator of house price developments as part of the monetary policy targets may result in welfare improvements, which can be sizeable; unfortunately, they are not systematic. Thus, not only do our results confirm the usual finding that reacting to house prices does not per se enhance the stabilization effectiveness of monetary policy. They also show that, in terms of (implicit) proximity to consumer welfare, rules in which house prices play a role can be outperformed by a standard rule which does not feature house prices at all.

Next, we analyse the case in which the monetary policymaker pursues the maximization of aggregate consumer welfare, which is measured using a second-order approximation to the households' utility function. We find that in this case the optimized rule does feature a systematic reaction to house price variations. The sign and size of such reaction crucially depend on the degree of nominal rigidities (house prices and nominal wages) and financial frictions (measured by the share of borrowers and the loan-to-value ratio) in the economy. We perform a sensitivity analysis to explore the contribution of such factors. Our main conclusions are the following: the presence of financial frictions per se does not alter the traditional prescription that the central bank should focus on relative price movements insofar as there is a substantial degree of nominal rigidity in each sector. In our case, allowing for a relatively small degree of house price stickiness (corresponding to an average duration of a house price of about two quarters) is sufficient to obtain a systematic positive response to house prices in the optimal simple rule. Moreover, the average level of the loan-to-value ratio matters. The optimal response to house prices is monotonically increasing in the loan-to-value ratio and becomes positive as soon as the latter reaches 90%.

Motivated by the results of our sensitivity analysis, we then move to study the properties of optimal monetary policy rules in an economy characterized by a higher degree of financial frictions compared to our baseline calibration. We show that, if the economy features both (i) a large share of constrained agents and (ii) a high average loan-to-value ratio, it becomes optimal for the central bank to systematically counteract house price movements. In such an environment, the central bank assigns a positive weight to the housing sector in the implicit overall consumer price index that it targets.

Finally, and related to the previous result, we show that uncertainty about the actual degree of financial frictions in the economy suggests some caution in the construction of optimal monetary policy rules. By resorting to a fault-tolerance analysis of the optimized rules in two model economies characterized by different degrees of financial imperfections, we document that sticking to a rule that features a positive systematic response to house price movements entails lower welfare costs, in case of mis-measurement of financial frictions, than sticking to a rule that features a negative response.

Our work relates to a number of previous contributions in the literature. Iacoviello (2005) uses a very similar model to study the case of a central bank that minimizes the weighted sum of the unconditional variances of inflation and output under technology, housing preference and inflation shocks. He estimates a monetary policy rule for the U.S. over the period 1974 Q1 - 2003 Q2 and computes the optimal weight to be assigned to housing inflation in such rule, letting the responses to inflation and output fixed at their estimated values. He finds that no stabilization gains arise from a positive systematic response to house price changes. In our first set of experiments we optimize over all the parameters in the rule, and obtain similar results. Several contributions (see Aoki (2001), Benigno (2004), Mankiw and Reis (2003) and Woodford (2003)) have established that, in the presence of multiple sources of nominal rigidities, the optimal rule should target the sectoral inflation indices using different weights, which are increasing functions of the degree of price stickiness in each sector and of the share of each good in the final consumption basket. In the presence of durable goods, Erceg and Levin (2006) have shown that a larger share than the one in consumption expenditure should be attributed to durable goods inflation in the optimal policy rule. More closely related to our study are the works by Mendicino and Pescatori (2005) and Rubio (2011), that analyse optimal monetary rules in the presence of housing and borrowing constraints. Both studies conclude that the aggressiveness of a central bank towards non-durable price inflation is reduced with respect to a standard New Keynesian model, because of the presence of collateral constraints. Intuitively, a higher inflation rate relaxes the borrowing constraint and enhances borrowers' welfare, all else being equal. Monacelli (2006) also reaches similar conclusions, performing a more general, fully-fledged Ramsey monetary policy exercise, which does not allow for an explicit characterization of the optimal policy rule as is done in our paper. In an applied contribution, Finocchiaro and Queijo von Heideken (2012) estimate the model of Iacoviello (2005) using quarterly data for U.S., U.K. and Japan and show that a non-negligible response to house prices is empirically plausible. They also show that, when the central bank minimizes a standard quadratic loss function, it is optimal to respond to house price movements, even though the corresponding gains are very small. None of the above-mentioned works provides a systematic and comprehensive comparison of alternative combinations of rules and objectives as we do here, nor they consider the role of financial frictions extensively.

In a recent study, Jeske and Liu (2012), using a two-sector DSGE model calibrated on U.S. data show that, although rental prices are sticky and should therefore be stabilized under the optimal monetary policy rule, asymmetries in factor intensities across sectors imply that the optimal response to rental inflation is actually smaller than what theory would predict in the case of symmetric sectors. Their model does not include credit constraints or any other type of financial frictions. In a recent contribution, Lambertini, Mendicino, and Punzi (2013) document the welfare gains obtained by letting the central bank react to fluctuations in housing and credit markets that are driven by expectations of future developments. While the sources of macroeconomic fluctuations are very different, both their paper and ours consider a micro-founded welfare function as the objective of the monetary policymaker. One important difference is that they consider Taylor rules and macro-prudential rules, while our paper only focuses on monetary policy.

The rest of the paper is organized as follows. Section 2 describes the model. Section 3 illustrates the calibration of the structural parameters. Section 4 outlines in detail the optimal monetary policy experiments based on the assumption that the monetary policymaker is concerned with business cycle stabilization. Section 5 considers the case in which the central bank directly pursues social welfare minimization and illustrates the dynamic properties of the model in response to different types of shocks, under different rules. Section 6 performs a sensitivity analysis. Section 7 analyses the role of financial frictions in the setting of monetary policy rules with particular reference to the response to house prices, by resorting to a fault-tolerance analysis. Section 8 concludes.

2 The model

We specify a closed-economy model where two final goods are produced: non-durable consumption and housing. We follow closely the framework illustrated in Darracq Pariès and Notarpietro (2008). The model economy includes two groups of agents, labelled *savers* and *borrowers*: the latter - who are relatively more impatient and have size $\omega \in (0,1)$ - face a collateral constraint, which links the amount of borrowing supplied by lenders to the value of a house (the existing collateral). Since in equilibrium all impatient agents behave as net borrowers and all patient agents as savers, we use the terms impatient/borrower and patient/saver interchangeably in the following.

2.1 Impatient households

Each impatient agent, denoted with a superscript b, maximizes the following stream of discounted utility:

$$E_0 \sum_{t=0}^{\infty} \left(\beta^B\right)^t \left\{ \frac{1}{1-\sigma_X} \left(X_t^b\right)^{1-\sigma_X} - \frac{\overline{L}_{C,b}}{1+\sigma_{L_{C,b}}} \left(N_{C,t}^b\right)^{1+\sigma_{L_{C,b}}} - \frac{\overline{L}_{D,b}}{1+\sigma_{L_{D,b}}} \left(N_{D,t}^b\right)^{1+\sigma_{L_{D,b}}} \right\} \quad (1)$$

where X_t^b is an index of consumption services derived from non-durable consumption $\left(C^b\right)$ and the stock of residential goods $\left(D^b\right)$, as follows:

$$X_t^b \equiv \left[\left(1-\varepsilon_t^D \omega_D\right)^{\frac{1}{\eta_D}} \left(C_t^b - h_b C_{t-1}^b\right)^{\frac{\eta_D-1}{\eta_D}} + \varepsilon_t^D \omega_D^{\frac{1}{\eta_D}} \left(D_t^b\right)^{\frac{\eta_D-1}{\eta_D}} \right]^{\frac{\eta_D}{\eta_D-1}} \quad (2)$$

The utility function features habit formation in non-durable consumption, captured by the term h_b. We introduce a housing preference shock, ε_t^D, which affects the marginal rate of substitution between non-durable and residential consumption.[2] Households receive negative utility from

[2] The shock is assumed to follow a stationary AR(1) process.

providing labor supply in each sector ($N^b_{C,t}$ and $N^b_{D,t}$, respectively). The specification of labor supply assumes that hours worked in the two sectors are perfect substitutes for households. The terms $\overline{L}_{C,b}$ and $\overline{L}_{D,b}$ are level-shift parameters used to normalize the impatient agent's labor supply in steady state.

All the impatient agents have limited access to the credit market and face a collateral constraint which, in real terms, reads:

$$b^b_t \leq \varepsilon^{LTV}_t (1-\chi) E_t \left\{ T_{D,t+1} D^b_t \frac{\pi_{t+1}}{R_t} \right\} \tag{3}$$

where $b^b_t \equiv \frac{B^b_t}{P_t}$ denotes real private debt, $\pi_{t+1} \equiv \frac{P_{t+1}}{P_t}$ is the gross inflation rate, R_t is the short-term nominal interest rate, $T_{D,t} \equiv \frac{P_{D,t}}{P_t}$ is the relative price of residential goods in terms of non-residential goods and $\chi \in (0,1)$ is the down-payment rate, so that $(1-\chi)$ approximates the loan-to-value ratio. The term ε^{LTV}_t denotes an exogenous shock to the loan-to-value ratio, which follows a stationary AR(1) process. The impatient household thus maximizes (1) subject to the collateral constraint (3) and the following sequence of real budget constraints:

$$C^b_t + T_{D,t}(D^b_t - (1-\delta) D^b_{t-1}) + \frac{R_{t-1}}{\pi_t} b^b_{t-1} = b^b_t + \frac{A^b_t + TT^b_t}{P_t} + \frac{W^b_{C,t} N^b_{c,t} + W^b_{D,t} N^b_{D,t}}{P_t} \tag{4}$$

where δ is the depreciation rate of the housing good, $W^b_{C,t}$ and $W^b_{D,t}$ denote the borrower's nominal wages in the two sectors, TT^b_t are government transfers and A^b_t is the stream of income derived from state-contingent securities, which allow the borrowers to hedge against wage income risk.[3] Further details about labor supply and wage setting are provided in Appendix A.

[3]We assume that the borrowers can trade such securities within their group, although they face financial frictions when borrowing from savers. Under separable preferences, trading such assets ensures that all borrowers have identical consumption plans in equilibrium.

2.2 Patient households

Patient agents, indexed with a superscript s, receive instantaneous utility from the same type of function specified for the impatient agents:

$$E_0 \sum_{t=0}^{\infty} \left(\beta^S\right)^t \left\{ \frac{1}{1-\sigma_X} \left(X_t^s\right)^{1-\sigma_X} - \frac{\overline{L}_{C,s}}{1+\sigma_{L_{C,s}}} \left(N_{C,t}^s\right)^{1+\sigma_{L_{C,s}}} - \frac{\overline{L}_{D,s}}{1+\sigma_{L_{D,s}}} \left(N_{D,t}^s\right)^{1+\sigma_{L_{D,s}}} \right\} \quad (5)$$

with $\beta^S > \beta^B$ and

$$X_t^s \equiv \left[\left(1-\varepsilon_t^D \omega_D\right)^{\frac{1}{\eta_D}} \left(C_t^s - h_S C_{t-1}^s\right)^{\frac{\eta_D - 1}{\eta_D}} + \varepsilon_t^D \omega_D^{\frac{1}{\eta_D}} \left(D_t^s\right)^{\frac{\eta_D-1}{\eta_D}} \right]^{\frac{\eta_D}{\eta_D - 1}} \quad (6)$$

where ε_t^D is the same housing preference shock introduced above.[4] The saver's real budget constraint reads:

$$\begin{aligned} C_t^s + T_{D,t}\left(D_t^s - (1-\delta) D_{t-1}^s\right) + I_t^s + b_t^s \quad = \quad & \frac{R_{t-1}}{\pi_t} b_{t-1}^s + \frac{W_{C,t}^s N_{C,t}^s + W_{D,t}^s N_{D,t}^s}{P_t} \\ & + \sum_{j=C,D} \left[R_t^{k,j} u_t^j K_t^j - \Phi\left(u_t^j\right) K_t^j \right] + \frac{A_t^s + \Pi_t^s + TT_t^s}{P_t} \end{aligned} \quad (7)$$

where K_t^j denotes the capital stock and u_t^j is the degree of capacity utilization. TT_t^s are government transfers to the savers group and Π_t^s are distributed profits (more below). As for the borrowers, we maintain the assumption that state-contingent assets are traded among the savers, in order to hedge against wage income. The corresponding stream of income is denoted A_t^s. As a result, all savers have identical consumption plans in equilibrium.

Capital is sector-specific. Patient agents own the full stock of capital and rent it out to intermediate-goods firms at the sector-specific rental rate $R_t^{k,j}$ $(j = C, D)$. Investment consists of the non-residential good only. The expression $R_t^{k,j} u_t^j K_t^j$ represents the sector-specific nominal return on the real capital stock, while $\Phi\left(u_t^j\right) K_t^j$ is the cost associated with variations in the degree of capital utilization.[5] The savers choose investment and capacity utilization in each

[4] We assume a common housing preference shock across agents, as a short-cut to capture a generalized increase in housing demand.

[5] Following Smets and Wouters (2007), we assume that the income obtained from renting out capital services depends on the level of capital augmented for its utilization rate. Moreover, the cost of capacity utilization is zero when capacity is fully used ($\Phi(1) = 0$). We assume the following functional form for the adjustment costs on

sector to maximize their intertemporal utility, subject to the intertemporal budget constraint and the capital accumulation equation:

$$K_t^j = (1-\delta_K)K_{t-1}^j + \left[1 - S\left(\frac{I_t^j}{I_{t-1}^j}\right)\right] I_t^j \tag{8}$$

where $\delta_K \in [0,1]$ is the depreciation rate of capital, S is a non-negative adjustment cost function formulated in terms of the gross rate of change in investment, I_t^j/I_{t-1}^j.

2.3 The non-residential goods sector

Final producers of the non-residential good operate in perfect competition and aggregate a continuum of differentiated intermediate goods. The elementary differentiated goods are imperfect substitutes with an elasticity of substitution denoted $\frac{\mu_C}{\mu_C - 1}$. Final goods are produced with the following technology $Y_t = \left[\int_0^1 Y_t(h)^{\frac{1}{\mu_C}} \mathrm{d}h\right]^{\mu_C}$. The corresponding demand-based price index is $P_t = \left[\int_0^1 p_t(h)^{\frac{1}{1-\mu_C}} \mathrm{d}h\right]^{1-\mu_C}$. As a result, individual demand for each good is defined as:

$$Y_t(h) = \left(\frac{p_t(h)}{P_t}\right)^{-\frac{\mu_C}{\mu_C - 1}} Y_t$$

Intermediate-goods producers, indexed with $h \in [0,1]$, are monopolistic competitors and produce differentiated products using a Cobb-Douglas function:

$$Z_t(h) = \varepsilon_t^A \left(u_t^C K_{t-1}^C(h)\right)^{\alpha_C} L_t^C(h)^{1-\alpha_C} - \Omega_C \qquad \forall h \in [0,1]$$

where ε_t^A is an exogenous technology process (following a stationary AR(1) process) and Ω_C is a fixed cost. Firms set prices on a staggered basis *à la* Calvo (1983): at any time t, a firm h faces a constant probability $1-\theta_C$ of being able to re-optimize its nominal price. The average duration between price changes is therefore $\frac{1}{1-\theta_C}$. We introduce price indexation by assuming that, if a firm cannot re-optimize its price, the price evolves according to the following simple rule:

$$p_t(h) = \pi_{t-1}^{\gamma_C} \overline{\pi}^{1-\gamma_C} p_{t-1}(h)$$

capacity utilization: $\Phi(X) = \frac{\overline{\overline{R^k}}}{\varphi}\left(\exp\left[\varphi\left(X-1\right)\right]-1\right).$

with γ_C denoting the degree of price indexation to past inflation and $\overline{\pi}$ being the long-run (steady state) inflation rate. Under the specified assumptions, in a symmetric equilibrium (with $p_t(h) = p_t \ \forall h$) the aggregate price index evolves as follows:

$$P_t^{\frac{1}{1-\mu_C}} = \theta_C \left(P_{t-1}\right)^{\frac{1}{1-\mu_C}} + (1-\theta_C)\widetilde{p}_t^{\,\frac{1}{1-\mu_C}}$$

where $\widetilde{p}_t$ is the price chosen by firm h to maximize its intertemporal profit.

2.4 The residential goods sector

Final producers of residential goods operate in perfect competition and aggregate a continuum of differentiated intermediate products. The elementary differentiated goods are imperfect substitutes with elasticity of substitution denoted $\frac{\mu_D}{\mu_D-1}$. Final goods are produced with the following technology $Z_{D,t} = \left[\int_0^1 Z_{D,t}(h)^{\frac{1}{\mu_D}} dh\right]^{\mu_D}$; we denote $p_{D,t}(h)$ the corresponding price. The aggregate residential price index is defined as $P_{D,t} = \left[\int_0^1 p_{D,t}(h)^{\frac{1}{1-\mu_D}} dh\right]^{1-\mu_D}$. Demand is allocated across the differentiated goods as follows: $Z_{D,t}(h) = \left(\frac{p_{D,t}(h)}{P_{D,t}}\right)^{-\frac{\mu_D}{\mu_D-1}} Z_{D,t}$.

Residential goods are produced using capital, labor and land. We assume that in each period of time the savers are endowed with a given amount of land, which they sell to the firms in a fixed quantity. The supply of land is exogenously fixed and each residential goods intermediate firm takes the price of land as given in its decision problem. Producers make use of a Cobb-Douglas technology as follows:

$$Z_{D,t}(h) = \varepsilon_t^{A_D} \left(u_t^D K_{t-1}^D(h)\right)^{\alpha_D} L_t^D(h)^{1-\alpha_D-\alpha_{\mathcal{L}}} \mathtt{L}_t(h)^{\alpha_{\mathcal{L}}} - \Omega_D \qquad \forall h \in [0,1]$$

where $\varepsilon_t^{A_D}$ is an exogenous sector-specific technology process, $\mathtt{L}_t(h)$ denotes the endowment of land used by producer h at time t and Ω_D is a fixed cost.

We allow for the presence of nominal price rigidity also in the residential sector. Firms are monopolistic competitors and set prices on a staggered basis à la Calvo (1983), with a constant probability $1-\theta_D$ of being able to re-optimize their nominal price in every period. Indexation to past and steady-state inflation is also allowed, so that, if a firm cannot re-optimize its price, the price evolves according to the following simple rule:

$$p_{D,t}(h) = \pi_{D,t-1}^{\gamma_D} \overline{\pi_D}^{1-\gamma_D} p_{D,t-1}(h)$$

with γ_D denoting the degree of price indexation to past sectoral inflation ($\pi_{D,t-1}$) and $\overline{\pi_D}$ being the long-run (steady state) inflation rate.

2.5 Government and monetary policy rule

The government finances the exogenous public spending G_t with agent-specific lump-sum transfers, denoted TT_t^B and TT_t^S, respectively.

Monetary policy is specified in terms of an interest rate rule:

$$\frac{R_t}{\overline{R}} = \left(\frac{R_{t-1}}{\overline{R}}\right)^{\rho} \left(\left(\frac{\pi_t}{\overline{\pi}}\right)^{\phi_\pi} \left(\frac{Y_t}{Y_{t-1}}\right)^{\phi_{\Delta y}}\right)^{1-\rho} \tag{9}$$

where an upperbar denotes the steady-state value of a given variable.

2.6 Market clearing conditions

Non-residential goods demand can be expressed as follows:

$$Y_t = \omega C_t^b + (1-\omega) C_t^s + I_t^C + I_t^D + G_t + \Phi\left(u_t^C\right) K_{t-1}^C + \Phi\left(u_t^D\right) K_{t-1}^D \tag{10}$$

while aggregate non-residential production satisfies:

$$Z_t = \varepsilon_t^A \left(u_t^C K_{t-1}^C\right)^{\alpha_C} \left(L_t^C\right)^{1-\alpha_C} - \Omega_C \tag{11}$$

so that the market clearing conditions in the non-residential goods market implies:

$$Z_t = \Delta_t Y_t \tag{12}$$

where $\Delta_t = \int_0^1 \left(\frac{p_t(h)}{P_t}\right)^{-\frac{\mu_C}{\mu_C - 1}} \mathrm{d}h$ is a measure of price dispersion among products.

Similarly, equating demand and supply in the residential good sector yields:

$$Z_{D,t} = \Delta_{D,t} \left[\omega \left(D_t^b - (1-\delta) D_{t-1}^b \right) + (1-\omega) \left(D_t^s - (1-\delta) D_{t-1}^s \right) \right] \tag{13}$$

where $\Delta_{D,t} = \int_0^1 \left(\frac{p_{D,t}(h)}{P_{D,t}} \right)^{-\frac{\mu_D}{\mu_D - 1}} \mathrm{d}h$ denotes price dispersion among non-residential intermediate goods.

3 Calibration

Table 1 summarizes the calibration of model parameters. The model is calibrated to replicate key features of the euro area economy. We rely on existing estimates where available. The savers' discount rate is set to 0.99, implying a steady-state interest rate of 4%; the borrowers' discount rate is 0.96, following Iacoviello (2005). We assume log utility for both type of agents, with labor supply elasticity σ_L equal to 2. The share of impatient agents, ω, is equal to 0.2, according to the estimates of Darracq Pariès and Notarpietro (2008) for the euro area. Regarding final consumption, habit persistence is set to 0.82 for the savers and 0.28 for the borrowers; the share of housing services in the utility function, ω_D, is chosen to pin down the steady-state ratio of residential investment to GDP. The intratemporal elasticity of substitution between durable and non-durable goods, η_D, is equal to one, thus implying a Cobb-Douglas specification for the consumption bundle X_t. The depreciation rate of housing, δ, is set to 0.01, corresponding to an annual rate of 4%. We set the down-payment ratio, χ, to 0.2, which implies a loan-to-value ratio of 80%, in line with the average for euro area countries.[6] About investment, the depreciation rate for physical capital is set to 0.03; the investment adjustment cost ϕ and the capital utilization cost ψ are set to 0.1 and 3, respectively, in the non-residential sector and to 0.005 and 10, respectively, in the residential goods sector. These values are chosen to match aggregate investment volatility (see Table 3, more below). About production, the relative share of capital is set to 0.3 in both sectors; the corresponding share of labor is 0.7 in the consumption sector and 0.55 in the residential sector, where the share of land, $\alpha_{\mathcal{L}}$, is set to 0.15. Elasticities of substitution across varieties in both the goods and the labor markets are set to 4.33, in order to

[6] See Calza, Monacelli, and Stracca (2013).

obtain a gross markup of 1.3. About nominal rigidities, we set the Calvo parameter $\theta_C = 0.92$, in line with the estimates of Smets and Wouters (2003, 2005), Christoffel, Coenen, and Warne (2008) and Adolfson et al. (2007). The indexation parameter is set to 0.5. We assume perfectly flexible prices in the residential sector, in line with Iacoviello and Neri (2010), Aspachs-Bracons and Rabanal (2011) and Forlati and Lambertini (2011).[7] Nominal wages are also assumed to be rigid: we set the Calvo parameter θ_w to 0.92 in both sectors. Such value is higher than the estimates reported in Christoffel et al. (2008). However, as observed in Iacoviello and Neri (2010), nominal wage rigidity is crucial for replicating the co-movement of real variables after technology and housing demand shocks. Therefore, given the relatively parsimonious stochastic structure of our model, we calibrate nominal wage stickiness to help the model replicate the observed standard deviations, as reported in Table 3.

Concerning the monetary policy rule (9), in our baseline specification we set $\rho = 0.85$, $\phi_\pi = 1.25$ and $\phi_{\Delta y} = 0.015$.

About the exogenous shocks, we set the persistence of technology shocks, ρ^A and ρ^{A_D}, to 0.9. For housing demand and loan-to-value ratio shocks, we set the corresponding persistence parameters to 0.95, in line with the estimated values reported in Iacoviello and Neri (2010) for the US and Darracq-Pariès and Notarpietro (2008) for the US and the euro area. A high degree of persistence in the exogenous processes for housing preference and financial shocks is needed to help the model replicate the observed volatility of housing prices and household debt. The choice of the standard deviation of the shocks is driven by the same motivation.

Table 2 reports the model steady-state ratios, which broadly replicate the figures for the euro area. Table 3 reports the model unconditional standard deviations, compared to the data.[8] We match the volatility of GDP, consumption and investment almost perfectly. For residential investment, the model-implied volatility is slightly above that observed in the data. Household debt volatility is the most difficult empirical feature to match, given the upward trend observed in the recent years. Still, the model-implied volatility falls short of the observed one by a relatively small amount. Nominal interest rate volatility is almost perfectly matched. The same holds true for consumption and housing inflation.

[7]In the sensitivity analysis we allow for a positive degree of nominal house price rigidity.

[8]We use linearly detrended data for the euro area over the period 1980 Q2 - 2010 Q1.

4 Business cycle stabilization

In our normative analysis we look for the optimal monetary policy in the class of simple interest rate rules. We assume that the central bank aims at minimizing some objective function (to be defined below) by adopting an interest rate rule that is *simple* and *operational*, according to the definition of Schmitt-Grohe and Uribe (2007). Namely, we restrict our attention to policy rules that (i) respond to variables that can be easily observed and (ii) deliver equilibrium determinacy. The general specification of such rules takes the form of equation (9). In the following, we analyse the scope for including also house prices in the interest-rate rule and/or in the central bank's objective function.

In this section we consider a central bank that responds to house price movements in a modified version of (9), to minimize a standard quadratic loss function with two arguments: the unconditional variances of consumer price inflation, π_t, and output, y_t[9]. We then extend the loss function to include house price growth. Clearly, as the two loss functions feature different arguments, a direct comparison of the respective minimized values is not allowed. Therefore, we assess the relative performance of the alternative policy regimes by evaluating the *welfare loss* attained under each optimized rule. The welfare loss is computed using a second-order approximation of the utility functions of the two agents in the economy. Such measure is invariant across rules and objective functions and is therefore suitable for the comparison of policy rules under alternative objectives. We provide details about welfare loss computations in Appendix B.

4.1 Standard loss function

We first consider a standard loss function, defined as a weighted average of the unconditional variances of consumer inflation and output, and an instrument rule that includes house prices among its arguments.[10] Formally, the central bank minimizes the following intertemporal loss

[9]See Taylor and Williams (2010) for a complete treatment of optimal simple rules in monetary policy analysis.

[10]As mentioned in the introduction, Iacoviello (2005) performs the same experiment with a similar model and a slightly different rule. In his analysis, however, the central bank only optimizes over the response to house prices, while all the other parameters are kept constant at their estimated values, obtained using U.S. quarterly data over the sample 1974Q1 - 2003Q2.

function:

$$\mathcal{L}_t \equiv E_t \left\{ \sum_{i=0}^{\infty} \delta^i \left[\pi_{t+i}^2 + \lambda Y_{t+i}^2 + \mu (\Delta R_{t+i})^2 \right] \right\} \tag{14}$$

by choosing the coefficients $\gamma_1, \gamma_2, \gamma_3$ and γ_4 in the rule:

$$\frac{R_t}{\overline{R}} = \left(\frac{\pi_t}{\overline{\pi}}\right)^{\gamma_1} \left(\frac{Y_t/\overline{Y}}{Y_{t-1}/\overline{Y}}\right)^{\gamma_2} \left(\frac{R_{t-1}}{\overline{R}}\right)^{\gamma_3} \left(\frac{\pi_{D,t}}{\overline{\pi_D}}\right)^{\gamma_4} \tag{15}$$

subject to the equations of the model economy.[11] It is well known (see Svensson (1999)) that as the intertemporal discount factor δ approaches one, the loss function $\mathcal{L}_t$ converges to its unconditional mean, denoted $E[\mathcal{L}_t]$. Hence, the central bank simply minimizes the following loss function:

$$\mathcal{L} \equiv E[\mathcal{L}_t] = \sigma_\pi^2 + \lambda \sigma_{\Delta y}^2 + \mu \sigma_{\Delta r}^2 \tag{16}$$

where σ^2 denotes the unconditional variance of a variable and the weights λ and μ are arbitrarily assigned by the policymaker.

Figure 1 shows the optimal policy frontiers for two alternative policy regimes: in the first one we set $\gamma_4 = 0$, thus imposing no response to house prices; in the second one we optimize over all the parameters in rule (15). Each frontier draws the optimal combinations of GDP and inflation variance, as the relative weight attached to output fluctuations, λ, varies in the range [0,1].[12] Clearly, the optimal frontier does not change in the two scenarios. Moreover, the optimal response to house price inflation is close to zero (see Table 4, more below). These results confirm the evidence in Iacoviello (2005): if a central bank is interested only in minimizing a linear combination of the variances of consumer price inflation and output, house prices do not provide any useful additional information.

4.2 Augmented loss function

We consider now the case of a central bank that has a preference over stabilizing house prices fluctuations, in addition to variations in consumer price and output. The period loss function

[11] The term $\Delta R_{t+i} \equiv R_{t+i} - R_{t+i-1}$ is included to penalize rules that imply wide variations in the nominal interest rate. See Rudebusch (2006) for an analysis of interest rate variability in the central bank's loss function.

[12] In the figure we report the case corresponding to μ=0.001. Results are robust to larger values for μ.

modifies as follows:

$$\mathcal{L} = \sigma_{\pi}^2 + \lambda\sigma_y^2 + \nu\sigma_{\pi_D}^2 + \mu\sigma_{\Delta r}^2 \tag{17}$$

When searching for the optimal coefficients in the rule (15), we do not impose the restriction $\gamma_4 = 0$ anymore: since the loss function now features housing inflation, it is natural to include the same variable in the information set of the monetary policymaker. We let ν move in the range $[0.001, 1]$. As already mentioned, a direct comparison of the minimum values of functions (17) and (16) is not possible, since the two objectives feature different arguments. Therefore, we assess the relative performance of the alternative policy regimes by evaluating the social welfare loss attained under each optimized rule, computed as a second-order approximation to the individual utility functions. Such approach has been largely used in the literature since the seminal work of Rotemberg and Woodford (1997) to rank the performance of alternative monetary policy rules.[13] More precisely, we compute the fraction of consumption streams that is to be added to each agent's consumption under each monetary policy rule, in order to achieve the corresponding individual steady-state welfare level. Appendix B provides additional computational details. Table 4 reports the minimum values for aggregate and individual welfare cost and the corresponding optimized coefficients. As a benchmark, in the first two rows we report the two cases analysed above, with a standard loss function and the two alternative rules considered (Taylor rule without and with a response to house prices, respectively), with the corresponding welfare losses. We focus on the case $\lambda = 0.5$, $\mu = 0.001$. As ν increases, the welfare cost attached to the policy rule that minimizes (17) initially declines, reaching a minimum for the aggregate (as well as individual) welfare cost around $\nu = 0.8$. Note that even with a relatively small weight for ν in the monetary policymaker's preference function (17), the resulting monetary policy rule implies a sizeable reduction in the associated welfare cost with respect to the case of $\nu = 0$; the reduction becomes very sizeable for ν larger than 0.5. Hence, even without explicitly pursuing a consumer welfare maximization policy, a monetary policymaker can do much better, in terms of consumer welfare, if the standard loss function is simply augmented with a term that (sufficiently) penalizes house price volatility.

The results reported in Table 4 refer to the case $\lambda = 0.5$. Similar conclusions can be drawn

[13]See Galí (2008) and Woodford (2003) for a discussion.

for a variety of values of λ, but not for all. Figure 2 reports the welfare loss associated with minimizing the standard loss function (equation (16); colour surface) and the welfare loss attainable when the policymaker's loss function also includes house prices (equation (17); transparent surface). In the latter case, the relative weight on house prices, ν, varies in the $[0, 1]$ interval. As a benchmark, the figure also reports the minimum welfare loss that can be achieved if the policymaker's objective function is given by the welfare of the average consumer (blue surface, see next section). Except for very small values of ν, the transparent surface lies *below* the coloured one. However, this is not the case when ν is smaller than 0.2. Actually, the lowest welfare cost is reached when $\nu = 0.01$ and the policymaker's loss function is given by (16) (i.e., house prices play no role at all). Hence, welfare considerations, even though not explicitly driving the monetary policymaker's actions, would implicitly suggest that the best the central bank can do is to assign no role to house prices.

Summing up, in line with previous results in the literature, there appears to be no room for house prices in monetary policymaking if the objective of the central bank is assumed to be the minimization of a standard loss function (or a slight variation of it). Moreover, we have documented that if one looks at the implied (and unintended, given the setup of the exercise) consequences for welfare, a policy that takes house prices into account can be outperformed by one that does not.

5 Welfare-maximizing monetary policy rules

In this section we consider the problem of a central bank that optimally chooses the coefficients in (15) to minimize the social welfare cost function. As already mentioned, such metric is microfounded, since it is derived from agents' preferences and model parameters. Moreover, using it as the central bank's objective function has the advantage of eliminating the choice of free parameters, such as λ and ν in (17).

Table 5 reports the results. The minimum welfare cost is attained when the rule is allowed to respond to house prices (first row). A higher welfare cost is obtained when the monetary policymaker does not target house price fluctuations, i.e. under the assumption that $\gamma_4 = 0$ in the rule (15). Also, responding to house prices makes both savers and borrowers better off, as reflected in a lower individual welfare cost (second and third columns, respectively). Notably, the optimal response to house price fluctuations is *negative* (last column), which implies that the central bank must lower the nominal interest rate in response to shocks that generate a surge in house prices. The finding that the optimal response to a movement in house prices is negative should not be regarded as completely unusual. Faia and Monacelli (2007) compute optimal interest rate rules in a model with credit market imperfections and heterogeneous households, where firms face agency costs that generate a countercyclical premium on external finance. In such framework, the optimal (in the sense of welfare-maximizing) response to asset prices is negative, as long as the response to the inflation rate is sufficiently mild; responding to asset prices becomes irrelevant, from a welfare perspective, when the anti-inflationary stance is particularly strong. In their model, the rationale for reducing interest rates in response to a surge in asset prices is related to alleviating the inefficiency in capital accumulation implied by credit market imperfections. In our setup, the presence of a perpetually binding borrowing constraints for the impatient household generates an inefficient response of consumption to, say, a housing demand shock. By lowering the interest rate in response to a surge in house prices, the monetary authority makes the borrowers better off, partially alleviating the inefficiency related to the borrowing limit. At the same time, the increase in inflation is detrimental to the savers. The optimal rule strikes a balance between these two opposite tendencies.

In the remainder of this Section we analyse the dynamic behavior of the economy in response to, alternatively, housing demand, financial and productivity shocks, when the optimal monetary policy rule is implemented. Figures 3 to 6 report the responses of the main macroeconomic variables under two alternative monetary policy rules: (i) the welfare-maximizing rule (solid blue line) and (ii) a standard Taylor-type rule with no response to house prices (dashed red line), with parameter values reported in Table 1.

5.1 Housing demand shock

An increase in housing demand drives up real house prices immediately (see Figure 3), as housing supply is kept from adjusting instantaneously by the fixed supply of land. A positive valuation effect is produced on the existing collateral, which allows the borrowers to increase non-durable consumption and debt. On the other hand, the savers increase lending and reduce consumption, due to the complementarity between non-durable consumption and housing in the utility function. Overall, the impact response of aggregate consumption is slightly positive (not reported). The dynamics of investment crucially depends on the response of the monetary policy rate. Under a standard Taylor rule that ignores house price fluctuations, the nominal interest rate is almost unchanged, largely reflecting inflation dynamics. Investment starts increasing only 6 quarters after the shock. Under the welfare-maximizing rule, the impact response of the policy rate to CPI inflation is much stronger (around 10 basis points in annualized terms). As the optimal response to house prices is negative, the latter increase more (almost 1 percent, as opposed to 0.8 under a Taylor rule), determining a larger collateral effect and a stronger consumption increase. Investment also increases, driven by the higher return on capital. The overall GDP response is larger and more persistent.

5.2 Financial shock

The dynamic effects of a shock to the loan-to-value ratio are qualitatively similar to those observed after a housing demand shock (Figure 4). The main difference is in the response of savers' consumption, which now increases instead of falling, reflecting the much smaller increase of real house prices after the shock. Again, the overall response of GDP is amplified under the welfare-maximizing monetary policy rule.

5.3 Technology shock

Figure 5 reports the responses to a technology shock in the non-residential sector. The negative impact on the inflation rate implies, under a simple Taylor rule, an increase in the real interest rate, which determines a fall in borrowers' consumption and an increase in investment. Under the welfare-maximizing rule the nominal interest rate falls by around 30 basis points (as opposed to less than 10), while inflation almost replicates the path observed with a Taylor rule. As a result, borrowers' consumption falls by a smaller amount. The same holds true for savers' consumption and investment, and GDP. Things are different when the shock hits the residential goods sector (Figure 6). As house prices are flexible in our benchmark parametrization, under a simple Taylor rule the nominal interest rate does not respond, mirroring the behavior of CPI inflation. The overall response of real variables is muted. To the opposite, under the welfare-maximizing rule the nominal interest rate has to increase in response to the fall in house prices. As a result, borrowers' consumption falls substantially, but its negative impact on GDP is compensated by the large positive response of investment, fuelled by the increase in the real interest rate.

6 Sensitivity analysis

In this section we perform a sensitivity analysis on some crucial parameters. First, we analyse the characteristics of welfare-maximizing rules under different assumptions about the degree of nominal rigidity in the economy: we consider in particular the degree of price stickiness in the residential goods sector and the degree of wage stickiness in both sectors. Second, we vary the degree of financial frictions in the economy by moving the share of borrowers and the loan-to-value ratio, one at a time. Finally, considering the stochastic structure of the model, we allow for different degrees of persistence of the housing demand shock.

6.1 Nominal rigidities in the residential sector

As mentioned in the introduction, a number of contributions[14] have established that, in the presence of multiple sources of nominal rigidities, the optimal interest rate rule should target the sectoral inflation indices using different weights, which are increasing functions of the degree of price stickiness in each sector and of the share of each good in the final consumption basket. However, in our baseline specification housing is both a flexible-price good and a durable good. Table 7 reports the optimal rules coefficients and the corresponding welfare costs for different degrees of house price stickiness. As the probability of not being able to reset prices, θ_D, increases, the optimal response to house prices becomes larger (smaller in absolute value) and turns positive for $\theta_D > 0.3$, i.e. for an average duration of a house price of about one and a half quarters. Hence, the presence of financial frictions does not seem to change the traditional prescription that the central bank should focus on relative price movements insofar as there is a substantial degree of

[14]See Aoki (2001), Benigno (2004), Mankiw and Reis (2003) and Woodford (2003).

nominal rigidity in each sector.[15]

6.2 Nominal wage rigidities

As suggested by Iacoviello and Neri (2010) and Aspachs-Bracons and Rabanal (2011), the role of nominal frictions in the labor market is crucial in explaining the co-movement between residential and non-residential goods after a housing preference shock. Table 8 reports the results obtained when we let the degree of nominal wage rigidity in both sectors vary. With perfectly flexible wages, the optimal response to house prices is zero. The welfare cost suffered by the savers is lower than in the baseline case, while it is larger for the borrowers. The second and third row of Table 8 report two alternative calibrations in which we set the degree of nominal wage stickiness and wage indexation in the two sectors to one half and three quarters of their baseline levels, respectively. Two results stand out: first, the optimal response to house prices moves from negative to slightly positive (virtually zero) as wage flexibility increases; second, the corresponding response to CPI inflation (γ_1) increases and becomes predominant in the limit-case of flexible wages. As wages adjust more frequently, the higher volatility of nominal wages generates larger volatility in price inflation, forcing the monetary authority to react more strongly to variations in the CPI, while at the same time ignoring the dynamics of house prices. In other words, as wage flexibility increases, the distortion generated by financial market imperfections is dominated by the inefficiency stemming from nominal price rigidity.

6.3 Varying the share of borrowers

We consider an alternative case of a model economy with two sectors (residential and non-residential goods) but no financial frictions. To do so, we set the share of borrowers to zero. Table 9 reports the results. In the first row we set $\theta_D = 0$, corresponding to perfectly flexible house prices: the resulting optimal response to house prices is zero. Comparing this result to the one reported in Table 5 (first row), we observe the following: the optimal response to house prices is larger (smaller in absolute value); the response to price inflation is smaller; the individual welfare cost incurred by the savers (which coincide with the whole household sector in this setup) is now

[15] Qualitatively similar results are obtained by letting θ_D vary in the same interval, while setting the degree of indexation in the residential goods sector to a non-zero value.

smaller than the one achieved in the economy with financial frictions. Intuitively, the presence of the borrowers in the objective function requires a more accommodative response of the interest rate. We then depart from the baseline case of flexible house prices and consider alternative assumptions on the degree of house price stickiness (rows 2-10). Without borrowers, when the degree of nominal price rigidity in the residential sector increases, the optimal response to house prices soon becomes positive, even for values of θ_D lower than 0.3. Overall, the results are qualitatively similar with and without financial frictions: the optimal response to house prices is an increasing function of the degree of house price stickiness.

We then consider the effects of increasing the share of borrowers, under both flexible and sticky house prices (Table 10 and Table 11, respectively). Under flexible house prices (see Table 10), a non-zero share of borrowers calls for a negative (but small in absolute value) response to house prices. The optimal response to CPI inflation and output is fairly stable with respect to changes in the share of borrowers (Table 10). The response to house prices is close to zero without borrowers; the optimal coefficient then smoothly declines to reach a minimum value of -0.1 in correspondence of a fraction of constrained agents in the economy between 0.2 and 0.3 and returns to zero when $\omega = 0.8$. In the intermediate case $\theta_D = 0.4$ (see Table 11), corresponding to an average duration of house prices of about one and a half quarters, we observe a qualitatively similar pattern (the optimal response to house prices is increasing in ω), although the optimal values of γ_4 are now larger.

6.4 Varying the loan-to-value ratio

Table 12 reports the results obtained when the loan-to-value (LTV) ratio is allowed to move from 99% to 60 %. For a very high degree of leverage (LTV ratio higher than 92%) the optimal response to house prices becomes positive. Its value declines as the ratio decreases, and becomes negative for a loan-to-value ratio of 80%. As the ratio goes below 80% (corresponding to our baseline calibration) the response to house prices remains fairly stable at an average value close to -0.15.

6.5 Persistence of housing demand shocks

Table 13 reports the results of the optimization exercise for different degrees of persistence of the housing demand shock, which is the main driver of short-run movements in house price in our model. It is quite natural to conjecture that the persistence of this shock may have an impact on the dynamics of house prices and real variables in general: a highly persistent shock implies in fact a higher predictability of future house prices.[16] In a recent contribution, Xiao (2013) uses the model of Iacoviello (2005) and shows that responding to house prices, in addition to output and inflation, helps stabilizing the economy (namely, it expands the determinacy region of the model) only if both private agents and the central bank do not possess current data on inflation and output and must forecast them, but do observe current housing prices. Hence, we explore the effects of changing the persistence of the housing demand shock, which, according to the stochastic structure of the model, should directly influence the forecastability of future house prices. However, as reported in the last column of Table 13, the optimal response to house prices is virtually unaffected by the persistence of the housing demand shock. Moreover, both individual and aggregate welfare costs are largely stable as ρ_D varies.

7 The role of financial frictions

In order to identify the main drivers of our results, we analyse the case of an economy characterized by a higher degree of financial frictions compared to our baseline calibration. We assume that (i) the share of constrained borrowers amounts to 30% of the population (as opposed to 20%) and (ii) the average loan-to-value (LTV) ratio is 90%, instead of 80%. We expect such economy to be more prone to displaying larger fluctuations in both prices and quantities, for two reasons. First, a higher LTV ratio provides the borrowers with more resources for any given quantity of collateral pledged, all else being equal. Hence, fluctuations in house prices, the real interest rate, or both, would result in larger fluctuations in the amount of debt compared to our baseline case, according to the standard financial accelerator mechanism (see Kiyotaki and Moore (1997)). Second, the presence of a larger share of borrowers further magnifies such amplification, via a mechanical effect on aggregate variables.

[16] We assume a stationary AR(1) process for the evolution of the housing preference shock ε_t^D.

Table 6 reports the results. The response to house prices is now positive: consistent with our expectations, in the presence of a more leveraged household sector the central bank has an incentive to counteract movements in house prices, which are more likely to generate wide oscillations in real variables in response to exogenous shocks of any type. Although we do not derive an analytical expression for the (utility-based) welfare criterion, such function will include a number of terms featuring, among others, non-durable consumption and housing services. As the degree of financial frictions increases, such variables will display larger fluctuations in response to, say, a housing demand shock, and therefore a central bank interested in minimizing the welfare cost will find it optimal to counteract the excess fluctuations by moving the interest rate adequately.[17]

It is instructive to compare the optimal weight attached to house prices in the rule obtained in this case to the weight of housing services in the individual utility functions (see equations (5) and (1)). In order to do so, we compute the optimal weight attached to housing inflation in an implicit overall consumer price index. Let us first define an overall price index π_t^O as follows:

$$\pi_t^O = \pi_t^{\alpha} \pi_{D,t}^{(1-\alpha)} \tag{18}$$

where $\alpha \in [0, 1]$. Plugging (18) into (15) gives:

$$\frac{R_t}{\overline{R}} = \left(\frac{\pi_t^O}{\overline{\pi}^O}\right)^{\gamma_1} \left(\frac{Y_t/\overline{Y}}{Y_{t-1}/\overline{Y}}\right)^{\gamma_2} \left(\frac{R_{t-1}}{\overline{R}}\right)^{\gamma_3}$$

where we have dropped the last term on the right-hand side: since house prices now enter the overall price index π_t^O, it is no longer necessary to target the two sectoral indices separately. Rewriting the last equation in log-deviations from steady-state levels (denoted with a "$\widehat{\ }$") and substituting the definition of π_t^O yields:

$$\widehat{r}_t \quad = \quad \gamma_1 \left(\alpha \widehat{\pi}_t + (1-\alpha)\widehat{\pi_{D,t}}\right) + \gamma_2 \left(\widehat{y}_t - \widehat{y}_{t-1}\right) + \gamma_3 \widehat{r}_{t-1}$$

Finally, substituting the optimized coefficients reported in Table 6, simple algebra gives the

[17] The example is merely illustrative: the argument would apply to all the shocks considered here. Notice that the welfare loss function features *unconditional* variances of model variables, just as the ad-hoc loss functions considered in the previous section.

following:

$$\widehat{r}_t = 1.77\,(0.98\widehat{\pi}_t + 0.02\widehat{\pi}_{D,t}) + 1.08\,(\widehat{y}_t - \widehat{y}_{t-1}) + 0.03\widehat{r}_{t-1}$$

As the last equation clearly shows, in an economy characterized by a large degree of financial frictions the optimal monetary policy rule prescribes an aggressive response to variations in the overall price index, where the housing sector receives a weight equal to 2%. Such weight is much lower than the share of housing services in consumption ($\omega_D = 0.1$) and is broadly comparable to the share of the residential sector in GDP (3%, see Table 2). Such result contrasts with the conclusion of Erceg and Levin (2006). In a recent work, Jeske and Liu (2012) perform a similar exercise, computing optimal monetary policy rules in a model of the U.S. economy with a residential and a non-residential sector, sticky rents and asymmetric labor intensity across sectors, but without financial frictions. They show that the optimal rule assigns a weight to rental price inflation that is much smaller than the housing expenditure share in the consumption basket (0.1 vs. 0.3, with roughly the same ratio between the two as in our experiment above). They attribute their result to the different degrees of factor intensity in the two sectors. In our case, the existence of a sufficiently large degree of financial frictions turns out to be sufficient to modify the traditional optimal monetary policy prescriptions in multi-sector models with multiple sources of nominal rigidities, i.e. that the central bank should assign weights to sectoral inflation indices that reflect both relative price stickiness and the expenditure shares of each sectoral good in final consumption.[18]

Having established the case for a systematic response to house price fluctuations as a consequence of financial frictions, we now analyse the robustness of our result, by means of a fault-tolerance analysis.

7.1 A fault-tolerance analysis

Fault-tolerance analysis of optimized interest-rate rules, as proposed by Levin and Williams (2003), provides useful insights onto the reasons that underlie our earlier findings. Fault-tolerance analysis is a concept borrowed from engineering and involves, in the present context, appraising the increase in the welfare loss function that results when a single parameter of an optimized

[18] See Aoki (2001), Benigno (2004) and Woodford (2003).

interest-rate rule is varied, holding the other parameters constant at their optimized values. A highly fault-tolerant model is one for which the parameters of the rule may vary over a relatively broad range of values without resulting in a large deterioration of its performance (in welfare terms). By contrast, an intolerant model would be a model whose performance deteriorates dramatically as soon as one deviates even modestly from some optimized parameter value (i.e., the welfare loss function exhibits strong curvature with respect to suboptimal variations in some parameter). We are interested in comparing the performance of our baseline economy, calibrated to replicate the main features of the euro area business cycle, to the one of an economy characterized by a larger degree of financial frictions, illustrated in the previous subsection. We aim at assessing, in particular, how much the welfare loss function increases as each parameter in the optimized monetary policy rule moves away from its optimal value. By measuring such variations we will be able to assess the scope for allowing the policymaker to deviate from optimal policy rules, with particular attention to the response to house price fluctuations. Figure 7 plots the fault tolerance of the two model economies to variations in the policy rules: each curve shows the change in the aggregate welfare loss function under the optimized rule (see Table 5, first row, and Table 6 for the corresponding values) as each single parameter is varied, with its minimum attained at the optimized value itself.

We perform the following thought experiment. Suppose that the central bank does not know with certainty the degree of financial frictions in the economy. Let us assume, for instance, that the policymaker acts as if the correct description of the euro area economy was the one implied by our baseline calibration, and implements the corresponding optimized monetary policy rule. What would be the cost of implementing such policy, if the true degree of financial imperfections was instead the one of our alternative calibration, namely $\omega = 0.3$ and $\chi = 0.1$? To answer this question, we compare the (minimum) value of the welfare loss implied by the optimal rule under the baseline calibration to the value of the welfare loss corresponding to the optimal rule with a high degree of financial frictions attained in correspondence of the same parameter value. In the case of the response to non-durable inflation, GDP growth and the lagged interest rate, the behavior of the welfare loss is qualitatively similar. In all cases, the additional loss generated by mistakenly enacting the "baseline" optimized rule amounts to about 0.07. When we focus on the response to house prices, instead, the value of such extra-loss almost doubles: in particular, as soon as the coefficient becomes negative, the welfare loss function corresponding to the "high financial frictions" economy increases very rapidly. To the opposite, graphical inspection of Figure 7 suggests that, if the central bank were to apply the optimized coefficient corresponding to the alternative calibration ($\gamma_4 = 0.03$) also in the baseline case, the corresponding additional loss would be much smaller (0.02). Such effects suggests some caution in adopting the optimized rule in our baseline economy, if the central bank is not fully sure about the values of ω and χ.

All in all, fault-tolerance analysis suggests that a systematic, positive response to house price fluctuations may not be pointless also in our benchmark model, if the monetary policymaker has a sufficient degree of uncertainty about the true amount of financial frictions that characterize the economy. A more detailed characterization of financial market imperfections, that possibly affect other elements of the economy than the household sector, would help the analysis of optimal monetary policy rules.

8 Conclusions

We develop a model of the euro area that includes house prices and a financial accelerator mechanism related to household borrowing, to analyse the scope for including house prices in the set of variables that the monetary policymaker targets and/or reacts to. Our main findings can be summarized as follows.

If the central bank's main objective is business cycle stabilization, i.e. the minimization of inflation and output fluctuations, then systematically responding to house prices does not entail any welfare improvement. This remains the case, to a large extent, even if the objective function includes the stabilization of house prices.

When the objective of monetary policy is instead the maximization of aggregate (and individual) welfare, the optimized rule does feature a systematic reaction to house price variations. The sign and size of such reaction crucially depend on the degree of nominal rigidities (house prices and nominal wages) and financial frictions (measured by the share of borrowers and the loan-to-value ratio) in the economy. Sensitivity analysis shows that allowing for a relatively small degree of house price stickiness (corresponding to an average duration of a house price of about two quarters) is sufficient to obtain a systematic positive response to house prices in the optimal simple rule. Moreover, the average level of the loan-to-value ratio matters. The optimal response to house prices is monotonically increasing in the loan-to-value ratio and becomes positive as soon as the latter reaches 90%.

Hence, the degree of financial frictions in the economy turns out to be of crucial importance in determining the response to house prices. If the economy is characterized by both (i) a large share of constrained agents (30%) and (ii) a high average loan-to-value ratio (90%), then it is optimal to systematically counteract house price movements. We have shown that in such an environment the central bank should assign a positive weight to the housing sector in an overall consumer price index. However, and different from previous results in the literature, such weight is lower than the corresponding share of housing services in the final consumption bundle.

Finally, and related to the previous result, uncertainty about the actual degree of financial frictions suggests some caution in the construction of optimal monetary policy rules. By resorting to a fault-tolerance analysis of the optimized rules in two model economies characterized by different degrees of financial imperfections, we have shown that the welfare cost entailed by a sub-optimal positive response to house price variations when the economy features less imperfections than the central bank estimates is substantially smaller than that implied by a negative response when financial frictions are larger than estimated.

Our results suggest that modelling financial imperfections, possibly also on the firms' side, seems of crucial relevance for the evaluation of monetary policy rules. We leave the investigation of the links between the two areas to future research.

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Appendix A. Labor supply and wage setting

The labor market structure is modelled following Schmitt-Grohe and Uribe (2006). Households of each type provide homogeneous labor services, which are transformed by monopolistically competitive unions into differentiated labor inputs. As a result, all household of the same type supply the same amount of hours worked in each sector, in equilibrium.

In each sector j $(j = C, D)$, we assume the existence of perfectly competitive labor packers, who buy the individual agents' labor supplies N^i_{jt} $(i = B, S)$ and aggregate them using a Cobb-Douglas function, to produce the aggregate labor indicators $L_{C,t}$ and $L_{D,t}$ that enter the firms' production function (more later). We specify the details of the labor packers profit-maximization problem below.

We also assume that in each sector j $(j = C, D)$ there exist monopolistically competitive labor unions indexed by i $(i = B, S)$, representing the patient and impatient households, respectively. Unions differentiate the homogeneous labor provided by households, creating a continuum of measure one of labor services (indexed by $z \in [0, 1]$) which are sold to the above-mentioned labor packers in each sector. Each union thus faces the following labor demand (originating from sector-specific labor packers):

$$L_{j,i,t}(z) = \left(\frac{W_{j,i,t}(z)}{W_{j,i,t}}\right)^{-\frac{\mu_w}{\mu_w - 1}} L_{j,i,t}$$

where $z \in [0, 1]$, $\mu_w = \frac{\theta_w}{\theta_w - 1}$ and $\theta_w > 1$ is the elasticity of substitution between differentiated labor services, which we assume to be constant across types and sectors. $L_{j,i,t}$ measures demand for labor type i by firms in sector j,

$$L_{j,i,t} = \left[\int_0^1 L_{j,i,t}(z)^{\frac{1}{\mu_w}} \mathrm{d}z\right]^{\mu_w}$$

while $W_{j,i,t}$ denotes the nominal wage set by union i in market j at time t[19]:

$$W_{j,i,t} = \left[\int_0^1 W_{j,i,t}(z)^{\frac{1}{1-\mu_w}} \mathrm{d}z \right]^{1-\mu_w}$$

Clearly, our structure gives rise to four different wages in equilibrium, each corresponding to a specific worker type (patient, impatient) in a specific sector (C, D). Every period, each union faces a constant probability $1 - \alpha_{wji}$ of being able to adjust its nominal wage. If the union is not allowed to re-optimize, wages are indexed to past and steady-state inflation according to the following rule:

$$W_{j,i,t}(z) = [\pi_{t-1}]^{\xi_w^{j,i}} [\overline{\pi}]^{1-\xi_w^{j,i}} W_{j,i,t-1}(z)$$

where $\pi_t = \frac{P_t}{P_{t-1}}$ and $\xi_w^{j,i}$ denotes the degree of indexation in each sector, for each type. Taking into account that unions might not be able to choose their nominal wage optimally in the future, the optimal nominal wage $\widetilde{W}_{j,i,t}(z)$ is chosen to maximize intertemporal utility under the budget constraint and the labor demand function. The first-order condition for the wage setting program of agent i in sector j can be written recursively as follows:

$$\frac{\widetilde{W}_{j,i,t}}{P_t} = \left(\mu_w \frac{\mathcal{H}_{1,t}^{wji}}{\mathcal{H}_{2,t}^{wji}} \right)^{\frac{\mu_w - 1}{\mu_w - 1}}$$

The resulting aggregate wage dynamics for each type in each sector is:

$$\begin{aligned}(W_{j,i,t})^{\frac{1}{1-\mu_w}} = {} & (1-\alpha_{wji}) \left(\mu_w \frac{\mathcal{H}_{1,t}^{wji}}{\mathcal{H}_{2,t}^{wji}} \right)^{-\frac{1}{\mu_w - 1}} \\ & + \alpha_{wji} \left(W_{j,i,t-1} \right)^{\frac{1}{1-\mu_w}} \left(\frac{\pi_t}{\pi_{t-1}^{\xi_{wji}} \overline{\pi}^{1-\xi_{wji}}} \right)^{\frac{-1}{1-\mu_w}}\end{aligned} \tag{19}$$

[19]The following definitions also hold:

$$N_{j,t}^B \equiv \int_0^1 L_{j,B,t}(z) dz$$

and

$$N_{j,t}^S \equiv \int_0^1 L_{j,S,t}(z) dz$$

where

$$\mathcal{H}_{1,t}^{wji} = \overline{L}_{j,i}\left(N_{j,t}^{i}\right)^{1+\sigma_{Lj,i}}\left(W_{j,i,t}\right)^{\frac{\mu_w}{\mu_w-1}} + \alpha_{wji}\beta_i E_t\left[\left(\frac{\pi_{t+1}}{\pi_t^{\xi_{wj,i}}\left[\overline{\pi}\right]^{1-\xi_{wj,i}}}\right)^{\frac{\mu_w}{\mu_w-1}}\mathcal{H}_{1,t+1}^{wji}\right] \tag{20}$$

and

$$\mathcal{H}_{2,t}^{wji} = \Lambda_{it}N_{j,t}^{i}\left(W_{j,i,t}\right)^{\frac{\mu_w}{\mu_w-1}} + \alpha_{wji}\beta_i E_t\left(\frac{\pi_{t+1}}{\pi_t^{\xi_{wj,i}}\left[\overline{\pi}\right]^{1-\xi_{wj,i}}}\right)^{\frac{1}{\mu_w-1}}\mathcal{H}_{2,t+1}^{wji} \tag{21}$$

with $\beta_i = \beta$ if $i = S$ and $\beta_i = \gamma$ if $i = B$. Also, $W_{j,i,t}$ denotes the real wage of type i in sector j and Λ_{it} is the marginal utility of consumption of type i.

We can now define the labor packers' Cobb-Douglas production function as follows:

$$L_j \equiv \omega^{\omega}(1-\omega)^{(1-\omega)}\left(\frac{N_{j,t}^{S}}{\Delta_{j,S,t}^{w}}\right)^{(1-\omega)}\left(\frac{N_{j,t}^{B}}{\Delta_{j,B,t}^{w}}\right)^{\omega}$$

where

$$\frac{N_{j,t}^{B}}{\Delta_{j,B,t}^{w}}W_{j,B,t} = \frac{N_{j,t}^{S}}{\Delta_{j,S,t}^{w}}W_{j,S,t}$$

and the term $\Delta_{j,i,t}^{w}$ denotes wage dispersion in sector j, related to agent i. Such term is a state variable that evolves as follows:

$$\begin{aligned}\Delta_{j,i,t}^{w} = &\left(1-\alpha_{wji}\right)\left(W_{j,i,t}\right)^{\frac{\mu_w}{\mu_w-1}}\left(\mu_w\frac{\mathcal{H}_{1,t}^{wji}}{\mathcal{H}_{2,t}^{wji}}\right)^{-\frac{\mu_w}{\mu_w-1}} \\ &+\alpha_{wji}\Delta_{j,i,t-1}^{w}\left(\frac{W_{j,i,t}}{W_{j,i,t-1}}\right)^{\frac{\mu_w}{\mu_w-1}}\left(\frac{\pi_t}{\pi_{t-1}^{\xi_{wj,i}}\left[\overline{\pi}\right]^{1-\xi_{wj,i}}}\right)^{\frac{\mu_w}{\mu_w-1}}\end{aligned}$$

Notice that wage dispersion is inefficient, as all job varieties are ex-ante identical (see SGU2006). The solution to the labor packers' cost-minimization problem also determines the following wage indices:

$$W_{j,t} = \frac{\left(W_{j,S,t}\right)^{1-\omega}\left(W_{j,B,t}\right)^{\omega}}{\omega^{\omega}(1-\omega)^{1-\omega}}$$

If wages were perfectly flexible, in every period t we would have:

$$\mu_w\overline{L}_{j,i}\left(N_{j,t}^{i}\right)^{\sigma_{Lj,i}} = \Lambda_{i,t}W_{j,i,t}$$

with $j = C, D$ and $i = P, I$. The real wage would be equal to a markup μ_w over the marginal rate of substitution between consumption and labor.

Appendix B. Welfare loss computations

Individual welfare measures are defined as follows:

$$\mathcal{W}_t^b \equiv E_0 \sum_{t=0}^{\infty} \left(\beta^b\right)^t \left\{ \frac{1}{1-\sigma_X} \left(X_t^b\right)^{1-\sigma_X} - \Delta_{C,b,t}^w \frac{\overline{L}_{C,b}}{1+\sigma_{L_{C,b}}} \left(N_{C,t}^b\right)^{1+\sigma_{L_{C,b}}} - \Delta_{D,b,t}^w \frac{\overline{L}_{D,b}}{1+\sigma_{L_{D,b}}} \left(N_{D,t}^b\right)^{1+\sigma_{L_{D,b}}} \right\}$$

and

$$\mathcal{W}_t^s \equiv E_0 \sum_{t=0}^{\infty} \left(\beta^s\right)^t \left\{ \frac{1}{1-\sigma_X} \left(X_t^s\right)^{1-\sigma_X} - \Delta_{C,s,t}^w \frac{\overline{L}_{C,s}}{1+\sigma_{L_{C,s}}} \left(N_{C,t}^s\right)^{1+\sigma_{L_{C,s}}} - \Delta_{D,s,t}^w \frac{\overline{L}_{D,s}}{1+\sigma_{L_{D,s}}} \left(N_{D,t}^s\right)^{1+\sigma_{L_{D,s}}} \right\}$$

for the impatient and patient agent, respectively, where $\Delta_{j,i,t}^w$ denotes wage dispersion in sector j, related to agent i. In order to evaluate the utility losses experienced by each agent under a given policy, we compute the fraction of consumption streams from an alternative policy regime (labelled ψ) that is to be added (or subtracted) to each agent's consumption in order to achieve the reference welfare level, corresponding to the steady state welfare. Formally, we solve the following equations:

$$\overline{\mathcal{W}^b} = E_0 \sum_{t=0}^{\infty} \left(\beta^b\right)^t \left\{ \frac{1}{1-\sigma_X} \left(X_t^{b,a}(1+\psi^b)\right)^{1-\sigma_X} - Delta_{C,b,t}^w \frac{\overline{L}_{C,b}}{1+\sigma_{L_{C,b}}} \left(N_{C,t}^{b,a}\right)^{1+\sigma_{L_{C,b}}} - Delta_{D,s,t}^w \frac{\overline{L}_{D,b}}{1+\sigma_{L_{D,b}}} \left(N_{D,t}^{b,a}\right)^{1+\sigma_{L_{D,b}}} \right\}$$

and

$$\overline{\mathcal{W}^s} = E_0 \sum_{t=0}^{\infty} \left(\beta^s\right)^t \left\{ \frac{1}{1-\sigma_X} \left(X_t^{s,a}(1+\psi^s)\right)^{1-\sigma_X} - Delta_{C,b,t}^w \frac{\overline{L}_{C,s}}{1+\sigma_{L_{C,s}}} \left(N_{C,t}^{s,a}\right)^{1+\sigma_{L_{C,s}}} - Delta_{D,b,t}^w \frac{\overline{L}_{D,s}}{1+\sigma_{L_{D,s}}} \left(N_{D,t}^{s,a}\right)^{1+\sigma_{L_{D,s}}} \right\}$$

where $\overline{\mathcal{W}^b}$ and $\overline{\mathcal{W}^s}$ denote the steady-state welfare level of the impatient and patient agent, respectively. Under our functional assumptions for the utility functions of the individuals, we have:

$$\psi^b = \left(\frac{\overline{\mathcal{W}^b} + \mathcal{W}_{t,L}^{b,a}}{\mathcal{W}_t^{b,a} + \mathcal{W}_{t,L}^{b,a}} \right)^{\frac{1}{1-\sigma_X}} - 1$$

and

$$\psi^s = \left(\frac{\overline{\mathcal{W}^s} + \mathcal{W}^{s,a}_{t,L}}{\mathcal{W}^{s,a}_t + \mathcal{W}^{s,a}_{t,L}} \right)^{\frac{1}{1-\sigma_X}} - 1$$

Finally, we compute an aggregate welfare cost as a weighted sum of individual welfare costs, as follows:

$$\psi \equiv \omega\psi^b + (1-\omega)\psi^s$$

Table 1. Calibrated parameters

Parameter	Description	Value
Preferences		
β^B	Discount factor (patient)	0.99
β^S	Discount factor (impatient)	0.96
σ_X	Intertemporal elasticity of substitution	1.00
σ_{L_C}	Labor supply elasticity (non-housing)	2.00
σ_{L_D}	Labor supply elasticity (housing)	2.00
ω	Share of impatient agents	0.20
Final consumption		
h_s	Habit persistence (patient)	0.82
h_b	Habit persistence (impatient)	0.28
ω_D	Share of housing services in consumption	0.10
η_D	Nondurable consumption–housing substitution	1.00
δ	Housing depreciation rate	0.01
χ	Downpayment ratio	0.20
Investment		
δ_K	Capital depreciation rate	0.03
ϕ	Investment adjustment cost (non-residential)	0.10
ψ	Capital utilization adjustment cost (non-residential)	3
ϕ_D	Investment adjustment cost (residential)	0.005
ψ_D	Capital utilization adjustment cost (residential)	10
Firms		
α_C	Share of capital (non-residential)	0.30
α_D	Share of capital (residential)	0.30
$\alpha_{\mathcal{L}}$	Share of land (residential)	0.15
μ_C	Intermediate non-residential goods substitution	4.33
μ_D	Intermediate residential goods substitution	4.33
μ_w	Labor varieties substitution (residential)	4.33
μ_w	Labor varieties substitution (non-residential)	4.33
Nominal rigidities		
θ_C	Calvo non-residential (goods)	0.92
γ_C	Indexation non-residential (goods)	0.50
θ_D	Calvo residential (goods)	0.00
γ_D	Indexation residential (goods)	0.00
θ_{w_C}	Calvo non-residential (labor)	0.92
γ_{w_C}	Indexation non-residential (labor)	0.23
θ_{w_D}	Calvo residential (labor)	0.93
γ_{w_D}	Indexation residential (labor)	0.44

Table 1. Calibrated parameters (continued)

Parameter	Description	Value
Monetary policy rule		
Interest-rate persistence	ρ	0.85
Response to inflation	ϕ_{π}	1.25
Response to GDP growth	$\phi_{\Delta y}$	0.015
Exogenous shocks: persistence		
Technology (non-residential)	ρ^{A}	0.90
Technology (residential)	ρ^{A_D}	0.90
Housing demand	ρ^{D}	0.95
Financial (loan-to-value)	ρ^{LTV}	0.95
Exogenous shocks: standard deviation		
Technology (non-residential)	σ^{A}	1.50
Technology (residential)	σ^{A_D}	1.10
Housing demand	σ^{D}	2.85
Financial (loan-to-value)	σ^{LTV}	0.01

Table 2. Steady state ratios

Variable	Description	Value
R	Nominal interest rate (annualized)	4.00
C/Y	Consumption-to-output ratio	0.58
$T_D Z_D/Y$	Residential investment-to-output ratio	0.03
I/Y	Investment-to-output ratio	0.21
$B/(4Y)$	Private debt-to-annual-output ratio	0.50
$P_H G/Y$	Public expenditure-to-output ratio	0.18

Table 3. Comparison of standard deviations

	Model	Data
GDP	2.54	2.21
Consumption	2.35	2.20
Investment	6.23	6.18
Residential investment	6.51	5.70
Household debt	8.07	5.84
Nominal interest rate	0.32	0.39
CPI inflation	0.32	0.46
House price inflation	0.99	1.03

Table 4. Loss function minimization: results ($\lambda = 0.5, \mu = 0.001$)

	$\mathcal{W}^{tot}$	$\mathcal{W}^{s}$	$\mathcal{W}^{b}$	γ_1	γ_2	γ_3	γ_4
Taylor	0.565	0.636	0.262	0.42	4.45	0.63	0.00
Taylor + house prices	0.569	0.640	0.267	0.38	4.01	0.63	0.01
HP ($\nu = 0.001$)	0.571	0.642	0.273	0.41	4.51	0.56	0.04
HP ($\nu = 0.2$)	0.531	0.577	0.336	0.18	1.01	0.28	0.18
HP ($\nu = 0.4$)	0.434	0.466	0.296	0.32	1.42	0.00	0.32
HP ($\nu = 0.6$)	0.390	0.416	0.278	0.45	1.66	0.00	0.45
HP ($\nu = 0.8$)	0.375	0.399	0.274	0.76	1.66	0.00	0.76
HP ($\nu = 1$)	0.383	0.407	0.278	6.39	17.29	0.00	6.39

Table 5. Welfare cost minimization: results

	$\mathcal{W}^{tot}$	$\mathcal{W}^{s}$	$\mathcal{W}^{b}$	γ_1	γ_2	γ_3	γ_4
Taylor + house prices	0.086	0.117	-0.041	2.36	1.84	0.08	-0.12
Taylor	0.091	0.118	-0.022	1.64	0.87	0.00	0.00

Table 6. Welfare cost minimization: the role of financial frictions

	ω	$LTV ratio$	$\mathcal{W}^{tot}$	$\mathcal{W}^{s}$	$\mathcal{W}^{b}$	γ_1	γ_2	γ_3	γ_4
Taylor + house prices	0.3	0.9	0.104	0.127	0.049	1.77	1.15	0.00	0.03

Table 7. Welfare cost minimization: nominal price rigidity in the residential sector

θ_D	$\mathcal{W}^{tot}$	$\mathcal{W}^{s}$	$\mathcal{W}^{b}$	γ_1	γ_2	γ_3	γ_4
0.1	0.092	0.123	-0.040	1.35	0.82	0.42	-0.06
0.2	0.097	0.128	-0.032	1.96	1.35	0.05	-0.04
0.3	0.105	0.135	-0.020	1.73	1.22	0.03	0.00
0.4	0.116	0.144	0.000	1.44	1.09	0.03	0.04
0.5	0.131	0.156	0.026	1.35	1.20	0.00	0.08
0.6	0.152	0.174	0.059	1.22	1.25	0.00	0.13
0.7	0.181	0.206	0.074	7.31	9.19	0.00	0.08
0.8	0.239	0.260	0.152	2.62	3.50	0.00	0.39
0.9	0.383	0.399	0.313	2.04	4.78	0.00	1.94

Table 8. Welfare cost minimization: nominal wage rigidity

	$\mathcal{W}^{tot}$	$\mathcal{W}^{s}$	$\mathcal{W}^{b}$	γ_1	γ_2	γ_3	γ_4
Wage flexibility	-0.030	-0.019	-0.076	5.14	0.00	0.68	0.01
Intermediate wage rigidity	-0.008	0.007	-0.073	3.51	0.45	0.81	-0.01
High wage rigidity	0.019	0.039	-0.065	2.37	0.70	0.53	-0.02
Benchmark calibration	0.086	0.117	-0.041	2.36	1.84	0.08	-0.12

Table 9. Welfare cost minimization: a benchmark model without borrowing

θ_D	$\mathcal{W}^{tot}$	$\mathcal{W}^{s}$	$\mathcal{W}^{b}$	γ_1	γ_2	γ_3	γ_4
0	0.092	0.092	-	1.71	1.42	0.00	0.00
0.1	0.094	0.094	-	1.67	1.45	0.00	0.02
0.2	0.097	0.097	-	1.65	1.52	0.00	0.04
0.3	0.100	0.100	-	1.63	1.57	0.00	0.06
0.4	0.106	0.106	-	2.02	2.19	0.00	0.07
0.5	0.114	0.114	-	2.72	3.20	0.00	0.10
0.6	0.126	0.126	-	7.45	9.50	0.32	0.13
0.7	0.141	0.141	-	2.63	3.17	0.00	0.24
0.8	0.174	0.174	-	2.82	3.34	0.00	0.45
0.9	0.269	0.269	-	3.75	4.27	0.00	1.74

Table 10. Welfare cost minimization: varying the share of borrowers

ω	$\mathcal{W}^{tot}$	$\mathcal{W}^{s}$	$\mathcal{W}^{b}$	γ_1	γ_2	γ_3	γ_4
0	0.092	0.092	-	1.69	1.42	0.00	0.01
0.1	0.092	0.105	-0.032	1.87	1.40	0.22	-0.08
0.2	0.087	0.118	-0.040	1.82	1.36	0.26	-0.10
0.3	0.082	0.136	-0.044	1.83	1.35	0.27	-0.10
0.4	0.081	0.162	-0.042	1.70	1.15	0.25	-0.08
0.5	0.081	0.201	-0.039	1.78	1.27	0.22	-0.07
0.6	0.085	0.259	-0.032	1.83	1.27	0.14	-0.05
0.7	0.094	0.353	-0.018	1.90	1.26	0.06	-0.01
0.8	0.111	0.523	0.008	1.94	1.28	0.11	0.00

Table 11. Welfare cost minimization: varying the share of borrowers ($\theta_D = 0.4$)

ω	$\mathcal{W}^{tot}$	$\mathcal{W}^{s}$	$\mathcal{W}^{b}$	γ_1	γ_2	γ_3	γ_4
0	0.106	0.106	0.039	1.96	2.12	0.00	0.07
0.1	0.114	0.124	0.018	1.97	1.92	0.00	0.04
0.2	0.116	0.146	-0.007	1.74	1.39	0.00	0.02
0.3	0.111	0.178	-0.044	1.83	1.49	0.00	-0.04
0.4	0.103	0.225	-0.081	0.07	1.55	0.00	-0.10
0.5	0.095	0.274	-0.085	1.64	1.67	0.00	-0.13
0.6	0.092	0.324	-0.062	1.55	1.49	0.00	-0.10
0.7	0.096	0.416	-0.040	0.06	1.48	0.00	-0.10
0.8	0.111	0.609	-0.014	1.80	0.00	0.00	-0.12

Table 12. Welfare cost minimization: varying the loan-to-value ratio

$LTV ratio$	$\mathcal{W}^{tot}$	$\mathcal{W}^{s}$	$\mathcal{W}^{b}$	γ_1	γ_2	γ_3	γ_4
0.99	0.157	0.161	0.142	9.06	0.87	0.00	0.40
0.98	0.135	0.126	0.174	3.51	3.71	0.00	0.07
0.96	0.122	0.114	0.155	1.84	1.50	0.00	0.07
0.94	0.111	0.111	0.110	1.96	1.60	0.00	0.04
0.92	0.103	0.109	0.077	1.61	1.08	0.03	0.03
0.9	0.098	0.110	0.046	1.81	1.25	0.01	0.00
0.8	0.087	0.117	-0.040	1.74	1.31	0.29	-0.10
0.7	0.089	0.125	-0.064	1.90	1.11	0.18	-0.11
0.6	0.092	0.128	-0.062	2.82	2.43	0.16	-0.19

Table 13. Welfare cost minimization: persistence of housing demand shock

ρ^D	$\mathcal{W}^{tot}$	$\mathcal{W}^{s}$	$\mathcal{W}^{b}$	γ_1	γ_2	γ_3	γ_4
0.1	0.205	0.248	0.026	1.61	1.76	0.66	-0.16
0.2	0.205	0.247	0.026	1.71	1.88	0.64	-0.17
0.3	0.204	0.246	0.026	1.80	1.95	0.60	-0.17
0.4	0.202	0.245	0.023	1.48	1.63	0.68	-0.15
0.5	0.200	0.242	0.021	1.61	0.17	0.64	-0.16
0.6	0.197	0.239	0.019	1.69	1.79	0.61	-0.16
0.7	0.191	0.232	0.014	1.65	1.77	0.63	-0.16
0.8	0.179	0.220	0.006	1.66	1.77	0.62	-0.16
0.9	0.146	0.184	-0.014	1.58	1.40	0.49	-0.12

Figure 1: Optimal policy frontiers (loss function minimization)

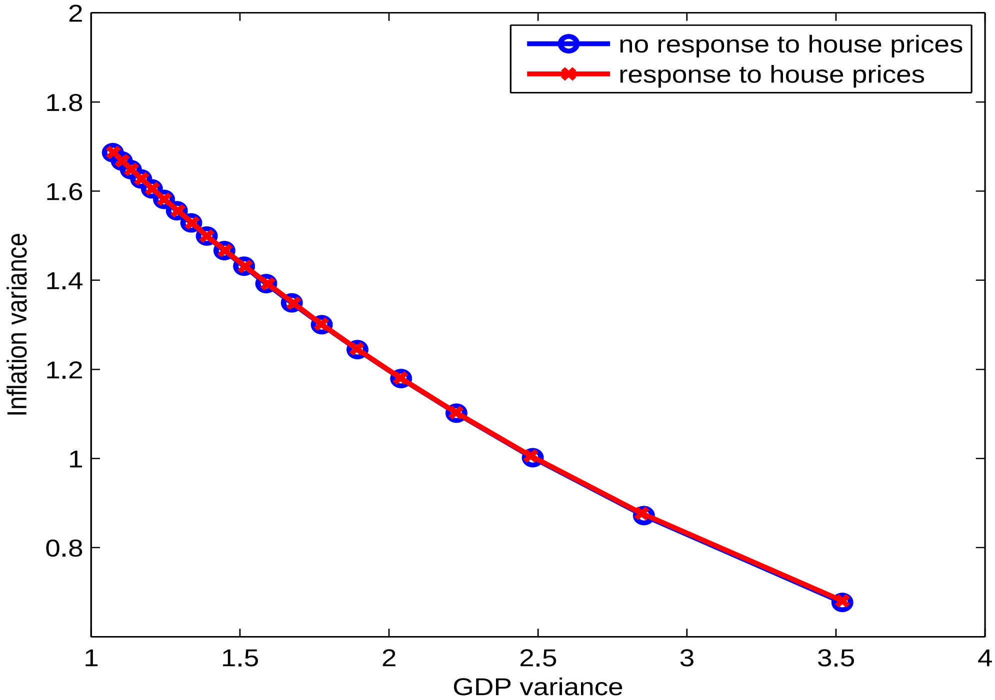

Figure 2: Welfare cost under alternative policy objectives. Vertical axis: total welfare loss. Horizontal axes: relative weight of output growth (left) and house price inflation (right) in the loss function

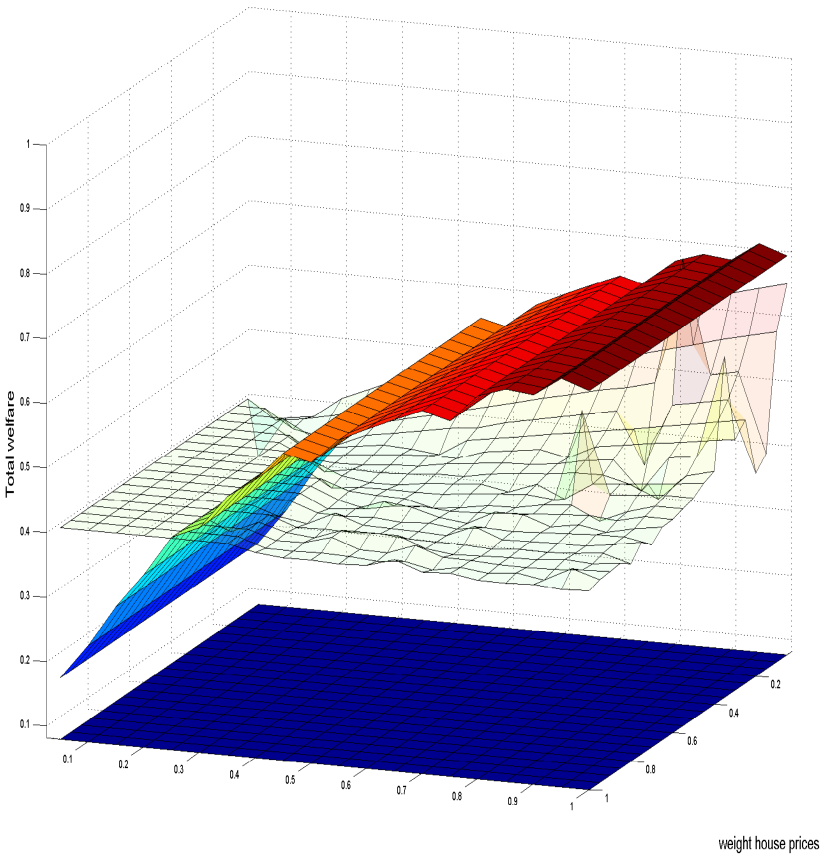

Figure 3: Impulse responses to a positive housing demand shock: optimal rule (solid blue line) and standard Taylor rule (dashed red line)

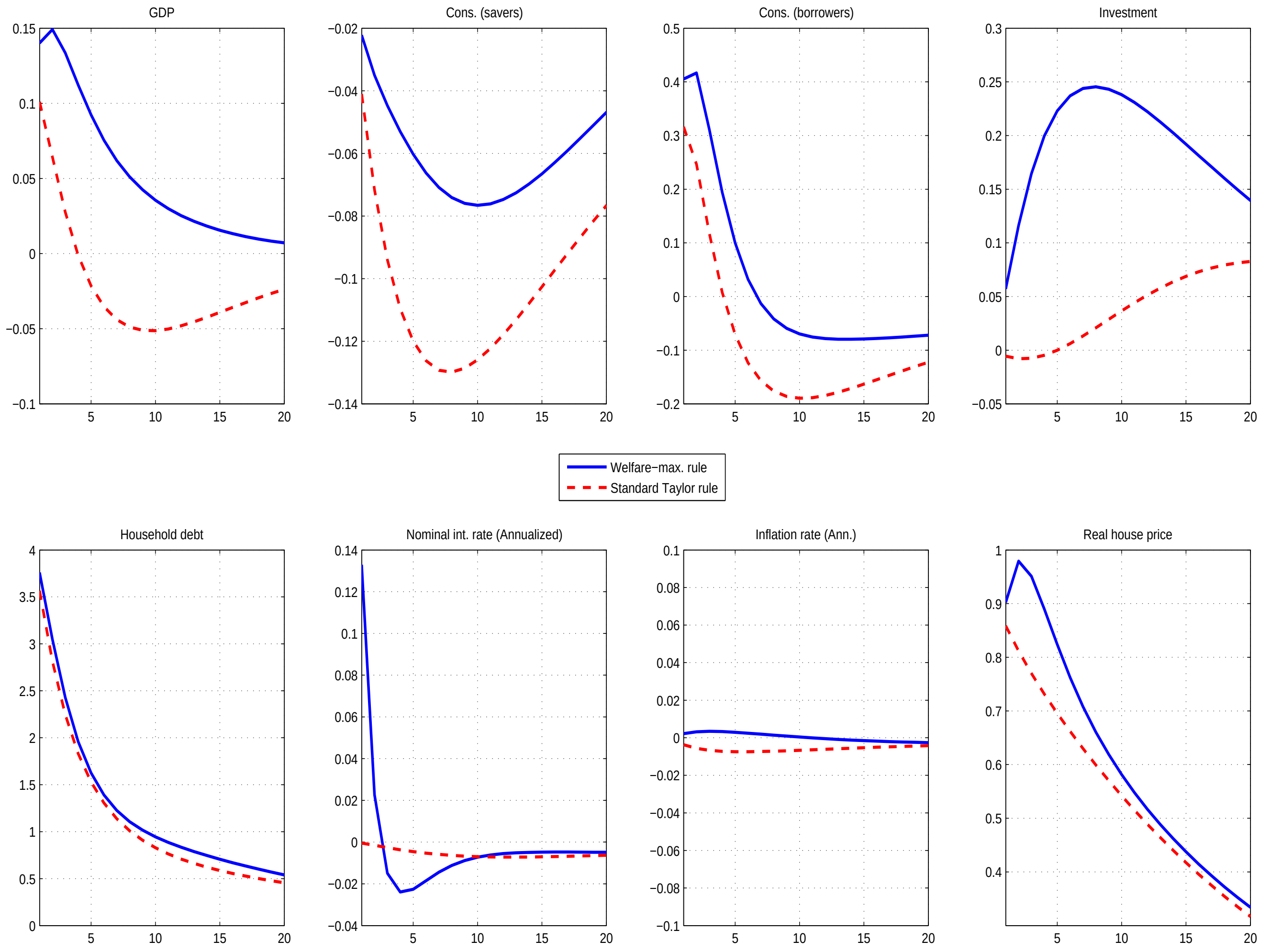

Figure 4: Impulse responses to a positive financial shock: optimal rule (solid blue line) and standard Taylor rule (dashed red line)

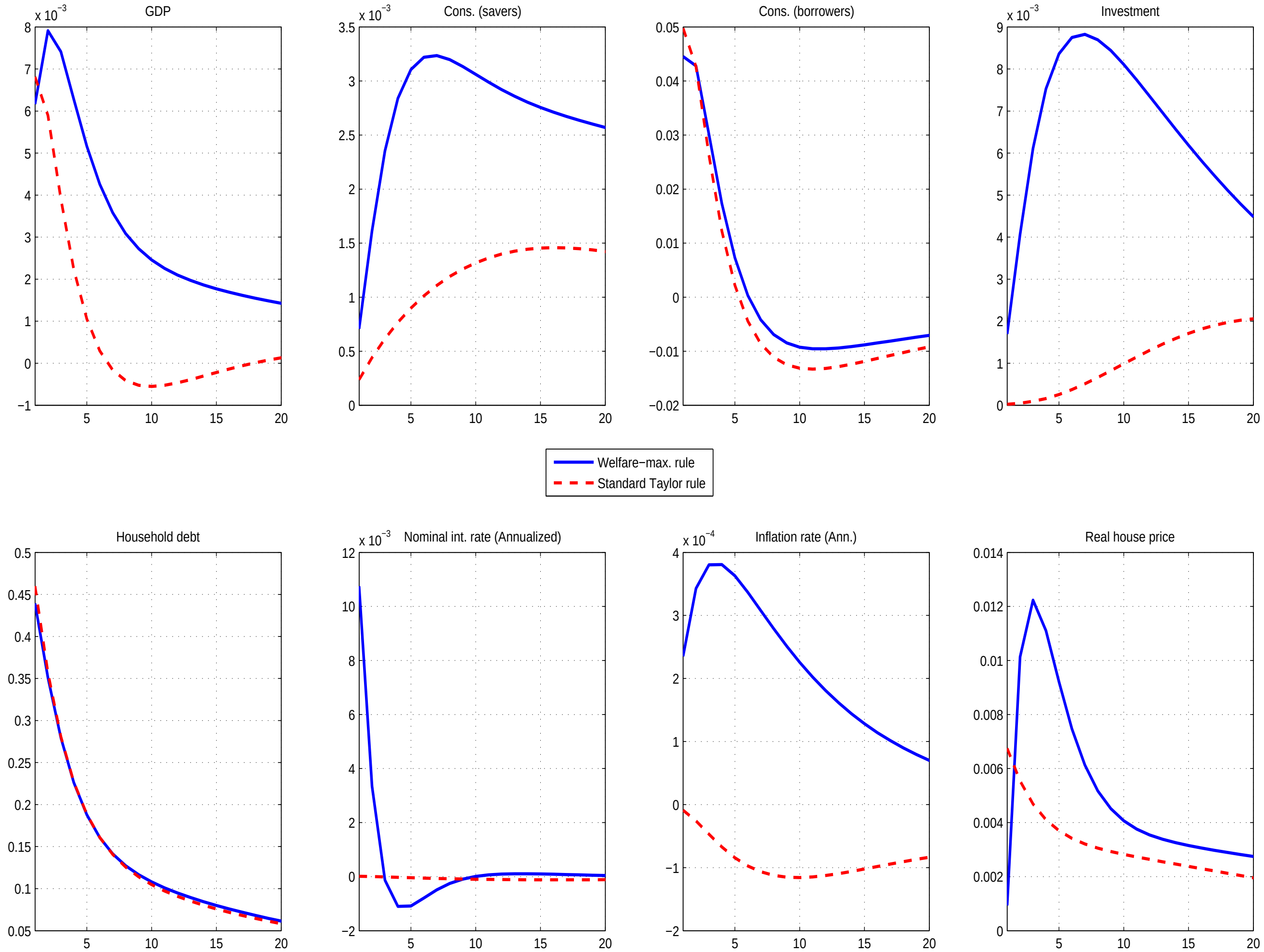

Figure 5: Impulse responses to a positive technology shock in the non-residential sector: optimal rule (solid blue line) and standard Taylor rule (dashed red line)

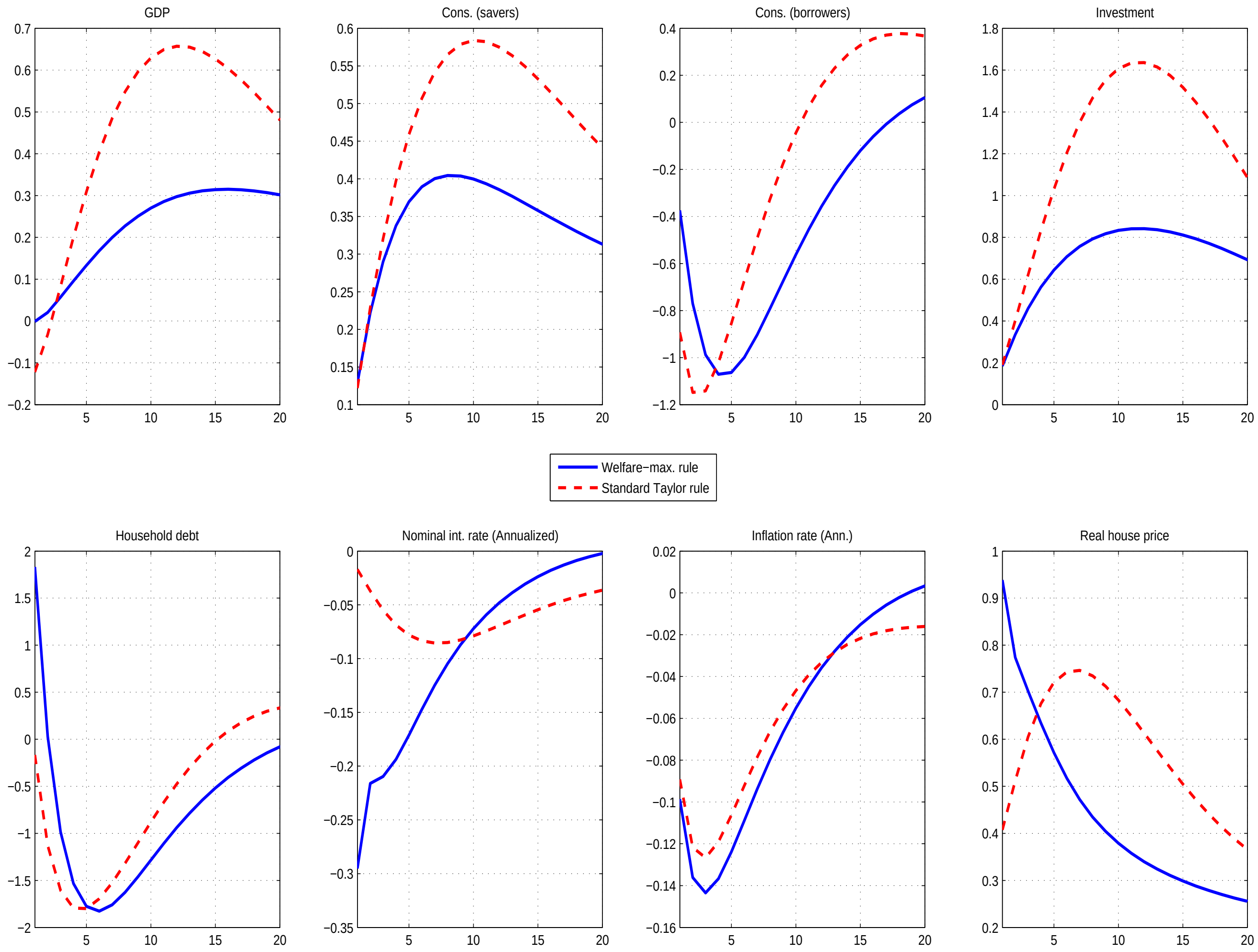

Figure 6: Impulse responses to a positive technology shock in the residential sector: optimal rule (solid blue line) and standard Taylor rule (dashed red line)

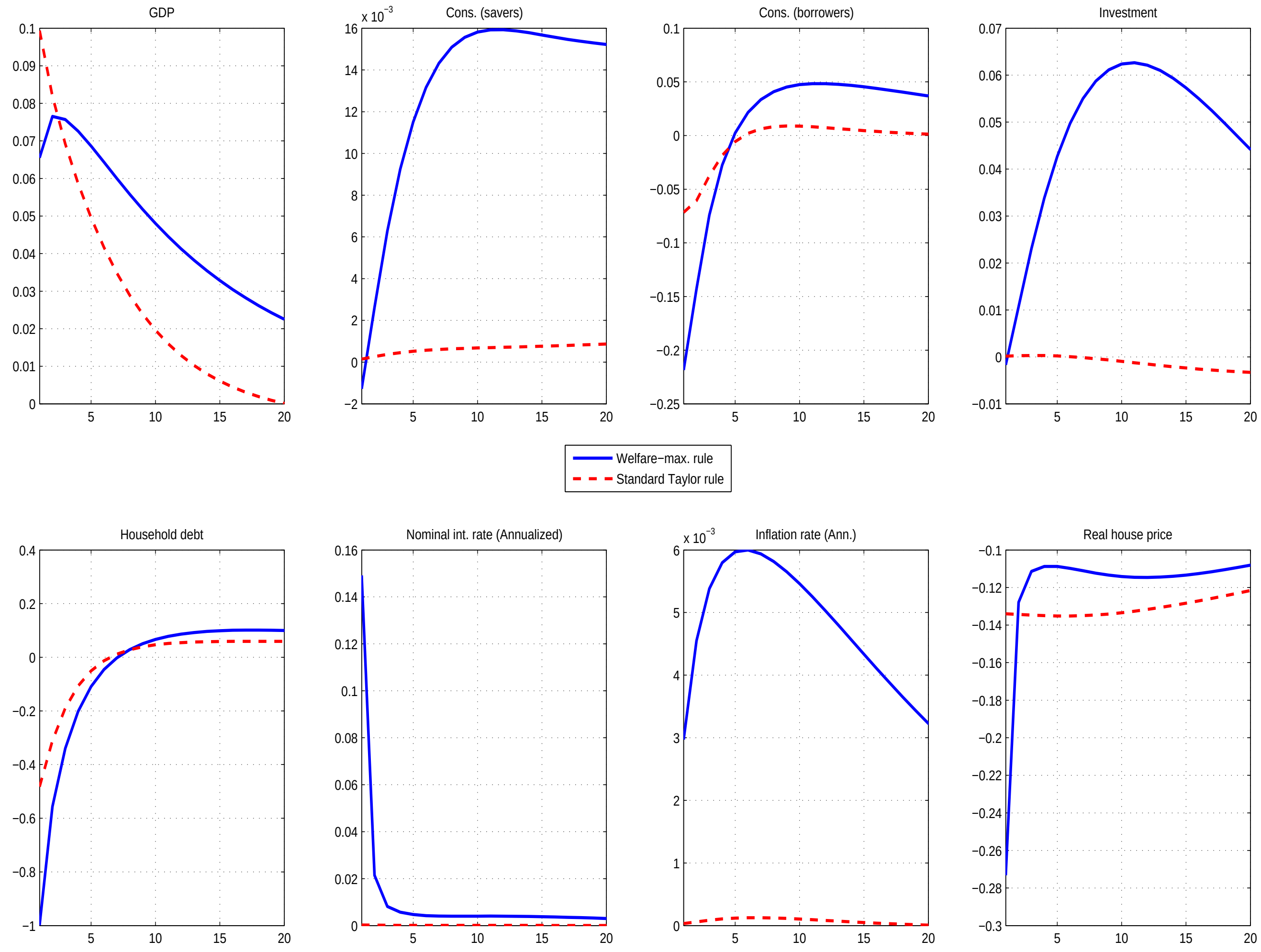

Figure 7: Fault tolerance: social welfare loss under optimal monetary policy rule, baseline calibration (solid blue line) and high degree of financial frictions (dashed red line)