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Macroprudential Debt-to-Income Ratio and Monetary Policy Rules

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Abstract

We consider a monetary DSGE model featuring a borrowing constraint such that the amount of debt cannot be larger than a fraction – the debt-to-income (DTI) limit – of borrowers' labor income and the DTI limit is endogenous. The coexistence of financial amplification mechanisms warranted by this model provides a role for a specific macroprudential tool: a countercyclical DTI limit. Conditional on the pre-crisis sample and in a more recent out-of-sample period, our *ex-post* normative analysis shows that when this policy is implemented the cooperation between central bank and macroprudential authority in pursuing the "two instruments for two goals" strategy delivers an efficient performance in terms of macroeconomic stabilization, significantly outperforming the central bank's policy of "leaning against the wind". This implies that a central bank should only be focused on its standard objectives (inflation and output stabilization) while financial stability be monitored by a macroprudential authority.

Keywords: household debt, house prices, loss function, macroprudential policy, monetary policy

JEL Classification: E32, E44, E52

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1 Introduction

A broad literature has documented that one of the most important causes of the financial crisis was the huge build-up in household debt that occurred prior to the burst of the bubble in the real estate sector (Glick and Lansing, 2011; Mian and Sufi, 2010). This has called into question the stance of the Fed during the credit boom, when the excessive accumulation of household debt became evident. The missing reaction of the Fed is often viewed a policy mistake with many academics advocating that the Fed should have raised the interest rate to curb the credit boom, i.e. "leaning against the wind" of over-borrowing (Borio and Lowe, 2002; Stein, 2013; Woodford, 2012).

This view is being challenged by an alternative theory which suggests that a more effective policy option is to implement specific macroprudential instruments, with the explicit purpose of safeguarding financial stability (Bank of England, 2011; IMF, 2013). According to this theory central banks should only be engaged in its primary goal of stabilizing inflation and output gap while a macroprudential authority monitors financial stability, i.e. a "two instruments for two goals" strategy (Svensson, 2012).

This paper contributes to this debate, investigating the effects of conducting monetary policy in interaction with a particular macroprudential policy: a countercyclical debt-to-income (DTI) limit. By means of a normative analysis we show that, during the pre-crisis credit boom, a cooperation central bank-macroprudential authority in pursuing the "two instruments for two goals" strategy – whereby the central banks seeks to stabilize inflation and output steering the interest rate while the macroprudential authority uses the macroprudential instrument to attain financial stability – would deliver an efficient performance in terms of macroeconomic stabilization, significantly outperforming the policy of "leaning against the wind" implemented by the central bank. In particular, we find that when the DTI limit reacts in a countercyclical way to household debt monetary policy yields a Pareto-improvement so that the "trade-off" between standard monetary policy objectives and financial stability is substantially resolved. Interestingly enough, in an out-of-sample experiment this result is shown to hold even after the crisis, during a period characterized by historically low interest rates and rising house prices.

Besides this normative analysis, the contribution of the paper also concerns a positive analysis. To simulate the credit boom phase we construct a monetary DSGE model in which the amount of borrowing is tied to borrowers' labor income in a collateral-like fashion á la Kiyotaki and Moore (1997). In this way, borrowers only request an amount of loans that is proportional to a given fraction – the debt-to-income (DTI) limit – of their income.

Crucially, in our model the DTI limit is not assumed constant, but endogenously driven by macroeconomic forces. This leads to an important finding: our model estimation proves that the DTI limit was positively correlated with house prices and the amount of borrowing before the crisis, suggesting that the DTI limit significantly loosened as postulated in other works (Pinto, 2011; Greenwald, 2018; Corbae and Quintin, 2015). Therefore, two distinct financial amplification mechanisms coexist and complement each other in our model with endogenous DTI limit. The first occurs through the appreciation of real estate values caused by a shock in the housing market. Unlike the standard collateral channel analysed in the literature (Iacoviello, 2005; Justiniano et al., 2015) the connection between high house prices and increasing leverage takes place through a slackening of the DTI limit: an increase in house prices is associated with a looser DTI limit, which ultimately leads to more borrowing. In this way, the "valuation" view, suggesting that the credit boom was most likely driven by an increase in housing demand, is here reconciled with the so-called "financial liberalisation" theory (Geanakoplos, 2010; Favilukis et al., 2017) which asserts that main culprit of the increase in leveraging was a slackening of credit conditions. In our model these two views are not contrasting, but complementary.

A second financial amplification stems from the presence of borrowers' labor income in the borrowing constraint. In fact, structural shocks that bring on an improvement of economic conditions spur borrowers' labor income, which ultimately prompts an increase in borrowing. In particular, a demand shock generates an increase in production which in turn leads to higher labor income and therefore more debt via the borrowing constraint. Instead, a supply shock calls for a reduction of the interest rate which boosts borrowers' labor income and house prices, so that the amount of new household debt requested slowly increases. This second amplification channel is consistent with the empirical finding that economic expansion is a strong precursor of a credit boom (Hofmann, 2001; Mendoza and Terrones, 2008; Dell'Ariccia et al. 2016).

These two financial amplification mechanisms, which are shown to contribute significantly to the credit boom phase, provides a strong motive for implementing a macroprudential policy. A countercyclical DTI limit turns out to be an effective instrument in dampening these amplification mechanisms and thus achieving financial stability.

The reminder of the paper is organized as follows. Section 2 presents the monetary DSGE model. Section 3 delineates the exercises that assess the stabilization effect of the macroprudential authority (implementing the countercyclical DTI limit) in cooperation with the central bank. In Section 4 we focus on the model dynamics, analysing impulse response functions and a counterfactual exercise. Section 5 discusses robustness exercises. Section 6 contains an out-of-sample experiment, in which the model is estimated over a shorter, more recent, sample. Finally, Section 7 summarizes results and concludes.

1.1 Related literature

The paper is related to works that use monetary DSGE models to investigate the stabilization effects of macroprudential policies in interaction with monetary policy. However, existing DSGE literature does not seem to focus on the the case of cooperation between monetary and macroprudential authority when the latter implements a countercyclical DTI limit.

Angelini et al. (2014) use an ad-hoc loss function to discuss how, when an economy is affected by financial shocks, a countercyclical capital requirement is effective in stabilizing output if this policy is implemented in cooperation with monetary policy. They conclude that macroprudential policies should complement the stabilization role of monetary policy. Kannan et al. (2012) consider a model with a financial accelerator mechanism generating credit boom and growth in house prices to show that implementing a macroprudential policy improves macroeconomic stability. They use a macroprudential policy designed as a rule according to which the central bank reacts to increasing levels of debt. Darracq Paries et al. (2011) build a DSGE model with financial frictions and document that the complementarity between financial regulation and a central bank responding to asset prices and credit growth is overall beneficial. Lambertini et al. (2013) study the potential benefits of rules for the loan-to-value (LTV) limit using a model in which the build-up of borrowing is driven by news shocks. The main result is that the loan-to-value ratio must react to financial variables in a countercyclical way. De Paoli and Paustian (2017) employ a New Keynesian model with a financial sector and a financial friction to show that coordination between the central bank and a macroprudential authority yields a more efficient stabilization than a non-cooperative game, regardless of whether the macroprudential policy is a liquidity requirement or is related to funding costs. Carrasco-Galego and Rubio (2014) find that the coordination between monetary policy and a macroprudential policy like the countercyclical LTV rule is welfare-improving for society. Collard et al. (2017) instead compute the Ramsey optimal policy with both monetary and macroprudential instruments, highlighting the benefits of a joint implementation. Angeloni and Faia (2013) build a model with risky banks to prove that countercylical macroprudential regulation and a "leaning against the wind" policy by the central bank are both desirable in terms of welfare. Closer to this work, Gelain et al. (2013) show that assigning more weight in the collateral constraint to borrowers' labor income relative to housing helps stabilize credit growth and house prices. However, they do not consider a countercyclical DTI limit, as done in this paper.

From a modelling perspective the paper belongs to the literature which considers an economy split between savers and borrowers and housing in the utility function. In this field a seminal paper is Iacoviello (2005), who builds a monetary business cycle model featuring housing in the utility function and heterogeneous agents where entrepreneurs are subject to a liquidity constraint tied to real estate values. His estimates show that an housing preference shock leads to a financial accelerator mechanism through the collateral constraint, which explains the positive response of nominal spending observed in US data. With a similar model Iacoviello and Neri (2010) show that housing demand shocks are an important driver of the business cycle. Guerrieri and Iacoviello (2017) includes occasionally-binding borrowing constraint and zero lower bound in order to show that housing preference shocks have an asymmetric impact, depending on whether the shock is positive or negative. Importantly, they argue that before the peak of the housing bubble the collateral constraint on housing was slack, while it became binding after the burst of the bubble in the real estate sector and the resulting collapse in house price. Based on this critical finding, we introduce an borrowing constraint whereby the amount of household debt is, instead, tied to labor income.

2 The DSGE model

The model is a modification of the monetary DSGE model used in Guerrieri and Iacoviello (2017). The economy is populated by borrowers and savers, who have different discount factors as borrowers are more impatient and therefore discount future at a lower discount factor. Standard Calvo-style New Keynesian features like price and wage rigidities are assumed. We depart from Guerrieri and Iacoviello (2017) with regard to the characterization of the borrowing constraint, which represents the key feature of the model. In particular, the amount of borrowing is not collateralized to real estate values, but tied to borrowers' labor income.

2.1 Borrowers

Borrowers maximize the following life-time expected utility function:

$$E_0 \sum_{t=0}^{\infty} \beta'^t z_t \left(\Gamma_c \log(c'_t - \varepsilon_c c'_{t-1}) + j_t \Gamma_h \log(h'_t - \varepsilon_h h'_{t-1}) - \frac{1}{1+\eta} n_t'^{1+\eta} \right), \quad (1)$$

where c'_t, h'_t, n'_t are borrowers' consumption, housing and labor supplied. Borrowers' budget constraint reads:

$$c'_t + q_t h'_t + \frac{R_{t-1} b'_{t-1}}{\pi_t} = \frac{w'_t n'_t}{\chi'_{w,t}} + q_t h'_{t-1} + b'_t + div'_t, \quad (2)$$

where b'_t is the amount of obligations (debt) in real terms, requiring a gross nominal interest rate R_t at the end of period t. The gross inflation rate is defined as: $\pi_t = P_t / P_{t-1}$. Borrowers earn labor income $w'_t n'_t$, where w'_t is real wage, paid by firms. The parameter $\chi'_{w,t}$ is the markup implied by the presence of monopolistic competition in the labor market, whereas div'_t are lump-sum profits gained by owning shares in unions and final goods firms. In each period borrowers purchase new housing

h'_t, at a real price q_t. The parameters ε^c and ε^h capture consumption habits, while Γ_c and Γ_h are set to ensure that the deterministic steady state of the marginal utility of consumption is independent of habits.
Housing services enter the utility function scaled by the exogenous process j_t. This can be interpreted as an institutional or exogenous modification of resources, which induces agents to purchase houses relative to other goods (Iacoviello and Neri, 2010). Another source of shock, common in the literature, is the preference shock z_t, which hits the whole utility function. We assume that these shocks follow AR(1) processes:

$$\log(j_t) = (1-\rho_j)j + \rho_j \log(j_{t-1}) + u_t^j, \tag{3}$$

$$\log(z_t) = \rho_z \log(z_{t-1}) + u_t^z, \tag{4}$$

where u_t^z, u_t^j are n.i.i.d. innovations with variance σ_z^2, σ_j^2, and j is the steady state value of j_t.
Borrowers are credit-constrained. In each period, the overall flow of obligations cannot exceed a fraction (DTI limit) of the current-period labor income:

$$b'_t \leq \gamma b'_{t-1} + (1-\gamma)\theta_t w'_t n'_t, \tag{5}$$

where θ_t is the debt-to-income (DTI) limit, and γ is some degree of inertia in the origination process of obligations.
Importantly, we assume that the DTI limit θ_t is endogenous and following the rule:

$$\log(\theta_t) = (1-\rho_\theta)\log(\theta) + \rho_\theta(\psi_q \log(q_t/q) + \psi_b \log(b'_t/b')), \tag{6}$$

where q and b' are steady state values of, respectively, house prices and household debt. This condition implies that the DTI limit can be related to the general level of house prices and household debt. The autoregressive component gauges the potential sluggishness of the changes in the DTI limit, and allows for a constant limit when $\rho_\theta = 0$.
This rule for the DTI limit is novel in the literature and thus deserves a detailed motivation. We underline three reasons. First, the specification (6) admits a relaxation of the DTI limit, which is found to be main responsible of the build-up of household debt in other papers using quantitative models (Corbae and Quentin, 2015; Greenwald, 2018). Moreover, the slackening of the DTI limit during the credit boom is widely consistent with empirical evidence highlighted in the literature. In this regard, Bokhari et. al. (2013) document that the share of DTI ratios increased massively from 1995 through 2007, explaining the soar (from 30% to 50%) of the ratio between mortgage debt and house values observed in the period between 1985 and 2007. Similar evidence is shown in Greenwald (2018), using Fannie Mae Single Family Dataset and Black Night data.
The second rationale is that main objective of the model is to fit as accurately as possible the credit boom phase. As will be shown later in the paper, the Bayesian estimation reveals that this specification is the best in terms of model fit. Importantly,

this occurs because this equilibrium condition allows to gauge some mechanisms explaining the credit boom phase. As an example, the rule permits a positive comovement between house prices and household debt which is, to a large degree, in line with the literature that highlighted the strong connection between real estate prices and credit supply (see, among the others, Mian and Sufi, 2011).
The third motivation has its foundations in the findings of Guerrieri and Iacoviello (2017), which show that a borrowing constraint whereby the amount of borrowing is collateralized to real estate values was presumably slack throughout 2001-2006, as house prices grew at a faster pace than household debt. This result provides a solid support for an alternative borrowing constraint such as an income-based one, that, instead, might have been binding during the credit boom.
Borrowers' maximization problem consists of maximizing utility (1), under the budget constraint (2) and the borrowing constraint (5), imposing that the DTI limit θ_t is exogenous for borrowers. The problem is solved by taking the first-order conditions with respect to the borrowers' control variables, that are consumption, housing, labor and debt.

2.2 Savers

Savers are endowed with the following life-time expected utility function:

$$E_0 \sum_{t=0}^{\infty} \beta^t z_t \left(\Gamma_c \log(c_t - \varepsilon_c c_{t-1}) + j_t \Gamma_h \log(h_t - \varepsilon_h h_{t-1}) - \frac{1}{1+\eta} n_t^{1+\eta} \right), \qquad (7)$$

where c_t, h_t, n_t are, respectively, consumption, housing and labor. Savers discount factor is larger than borrowers' one ($\beta' < \beta$), as savers are less impatient. Savers' per-period budget constraint is written in the following way:

$$c_t + q_t h_t + b_t + i_t = \frac{w_t n_t}{\chi_{w,t}} + q_t h_{t-1} + \frac{R_{t-1} b_{t-1}}{\pi_t} + r_{k,t} k_{t-1} + div_t, \qquad (8)$$

where b_t is the amount of one-period assets (loans) in real terms held at the end of period t, which accrue the interest R_t in $t+1$, whereas $w_t, \chi_{w,t}$ and div_t are real wage, monopolistic mark-up in the labor market and dividends rebated to savers. Unlike borrowers, savers accumulate capital from the previous period k_{t-1} and invest resources i_t in new capital, where $r_{k,t}$ is the return of capital. Therefore, gross capital evolves over time according to the following law of motion:

$$k_t = a_t \left(i_t - \frac{\phi}{2} \left(\frac{\Delta i_t^2}{i} \right) \right) + (1 - \delta_k) k_{t-1}, \qquad (9)$$

whereas capital depreciates at a constant rate δ_k. An exogenous disturbance a_t hits new capital for a given level of investment. This shock is also modelled as an AR(1) process:

$$\log(a_t) = \rho_k \log(a_{t-1}) + u_{k,t}, \qquad (10)$$

where $u_{k,t} \sim N(0, \sigma_k^2)$.
Hence, savers' maximization problem consists of maximizing utility (7), under the budget constraint (8) and the law of capital accumulation (9). This problem is solved by taking the first-order conditions with respect to the savers' control variables, i.e. consumption, housing, labor, investment, capital and assets.

2.3 Firms

The supply side of the economy features perfectly competitive wholesale firms producing final goods and monopolistically competitive firms producing intermediate goods. Wholesale firms combine capital and labor supplied from savers and borrowers solving:

$$\max \left(\frac{y_t}{\chi_{p,t}} - w_t n_t - w_t' n_t' - r_{k,t} k_{t-1} \right), \tag{11}$$

where $\chi_{p,t}$ is the monopolistic markup gained by intermediate good firms.
Each intermediate good is produced by adopting the following production function:

$$y_t = n_t^{(1-\sigma)(1-\alpha)} n_t^{'\sigma(1-\alpha)} k_{t-1}^{\alpha}, \tag{12}$$

where σ represents borrowers' labor income share, namely their contribution to production.
Intermediate good firms set price as in Calvo's model: only a fraction $1 - \mu_\pi$ of firms (with $0 < \mu_\pi \leq 1$) can optimize the price in each period, while the remaining μ_π firms anchor the price to the inflation target $\bar{\pi}$. A Phillips curve is therefore derived:

$$\log(\pi_t/\bar{\pi}) = \beta E_t \log(\pi_{t+1}/\bar{\pi}) - \varepsilon_\pi \log(\chi_{p,t}/\bar{\chi_p}) + u_{p,t}, \tag{13}$$

where $\varepsilon_\pi = (1-\mu_\pi)(1-\beta\mu_\pi)/\mu_\pi$ measures the sensitivity of inflation to changes in the markup, and $u_{p,t}$ is a n.i.i.d. disturbance.
Wholesale firms demand labor services from labor packers, which reassemble labor services supplied by borrowers' and savers' unions. These unions compete in a monopolistic fashion and set respective wages à la Calvo. Log-linearization of unions' pricing rules deliver wage inflation Phillips curves for both savers and borrowers:

$$\log(\omega_t/\bar{\pi}) = \beta E_t \log(\omega_{t+1}/\bar{\pi}) - \varepsilon_w \log(\chi_{w,t}/\bar{\chi_w}) + u_{w,t}, \tag{14}$$

$$\log(\omega_t'/\bar{\pi}) = \beta' E_t \log(\omega_{t+1}'/\bar{\pi}) - \varepsilon_w' \log(\chi_{w,t}'/\bar{\chi_w'}) + u_{w,t}, \tag{15}$$

where $\omega_t = (w_t \pi_t / w_{t-1})$, $\omega_t' = (w_t' \pi_t / w_{t-1}')$ are wage inflation for each agent type, and $u_{w,t}$ is a n.i.i.d wage markup shock.

2.4 Central bank

The monetary authority is responsible of setting the nominal interest rate. This is set according to the Taylor-like monetary rule:

$$R_t = R_{t-1}^{r_r} R^{(1-r_r)} \left(\frac{\pi_t^A}{\bar{\pi}^A}\right)^{(1-r_r)r_\pi} \left(\frac{y_t}{y}\right)^{(1-r_r)r_y} e_t, \tag{16}$$

where $\pi_t^A = (P_t/P_{t-4})^{0.25}$ is the annual inflation rate, while variables without index are respective steady state values. The persistence of the central bank's action is captured by r_r, whereas r_y and r_π govern the reaction to output and year-on-year inflation respectively. We allow for a monetary policy shock e_t which is modelled as:

$$\log(e_t) = \rho_r \log(e_{t-1}) + u_{r,t} \ , \tag{17}$$

with $u_{r,t} \sim N(0, \sigma_r^2)$. It is important to point out that this structural shock helps estimate relevant parameters values, like those of the Taylor rule (16), and improves the overall fit of the model in the Bayesian estimation. However, in our simulations we shut down this shock, as subject of the paper is to study the stabilization effect of monetary policy.

Market clearing conditions in the assets and housing market close the equilibrium of the model. The full list of model equilbrium conditions is reported in Appendix A.

2.5 Estimation

We estimate the baseline model with standard Bayesian techniques. Details of data used for estimation and their transformation are laid out in Appendix B. We consider six observable variables: consumption, investment, interest rate, price inflation, wage inflation and house prices. The model features six structural shocks: price markup, wage markup, investment, intertemporal preference, housing preference and monetary policy shock. As in Guerrieri and Iacoviello (2017) we do not include household debt as an observable because the mapping between this variable in the model and its correspondent on data is not perfect, as in the model debt can only be taken on by constrained agents. Quarterly series range from 1977:Q2–2006:Q4. We choose this timespan because we are only focusing on the credit boom phase.

Model parameters are calibrated as in Table 1. Overall, they are consistent with Guerrieri and Iacoviello (2017). Savers' discount factor $\beta = 0.995$ implies an annual interest rate equal to 4% in the steady state. As for the steady state inflation, $\bar{\pi} = 1.005$ means a 2% annual inflation rate.

For our purposes, the most interesting calibration concerns the debt-to-income limit in the steady state. We set the DTI limit to 40%, as in Mendoza (2002). Remarkably, this value is within the range of the calibration used by Greenwald (2018), i.e. a limit equal to 36%, and the 43% established by the "Consumer Financial Protection Bureau" in January 2014 for qualified mortgages.

Table 1: Calibration of parameters of the DSGE model

Parameter		Value
β	savers discount factor	0.995
β'	borrowers discount factor	0.99
$\bar{\pi}$	inflation target	1.005
η	inverse of Frisch elasticity of labor	1
ϵ	steady state elasticity among goods	6
θ	steady state debt-to-income limit	0.4
j	steady state housing weight in utility function	0.07
α	capital share in production	0.3
δ_k	capital depreciation rate	0.025
χ_p	steady state price markup	1.2
χ_w	steady state wage markup	1.2

The priors used for our Bayesian estimation are consistent with Guerrieri and Iacoviello (2017). Two novel parameters are ψ_b and ψ_q. We assume that their prior distribution is a Normal density function centred at zero, which implies that point estimates can be both positive and negative. Moreover, loose variances (equal to 1) ensure that they can deviate from the mean to a large extent.

Most notably, our estimation delivers a positive value for both parameters ψ_b and ψ_q: posterior means are, respectively 0.579 and 2.150 (Table 2). Therefore, the fact that the DTI limit displays (on average) a positive co-movement with the level of household debt and, to a larger degree with house prices implies that financial amplification mechanisms have played a significant role in the credit boom observed before the 2008 financial crisis.

Other posterior estimates are in line with previous studies. As for the parameters in the Taylor rule, the interest rate inertia has mean equal to 0.391, while 1.392 and 0.114 are mean estimates of central bank's responses to, respectively, inflation and output. Regarding structural shocks, one can note a very large persistence of the housing preference shocks (0.983) which is consistent with findings in Guerrieri and Iacoviello (2017). In Appendix B we report the historical variance decomposition of consumption and house prices.

A crucial assumption of the model is the rule for the DTI limit, specified by equation (6). A modification of this rule can substantially affect the way in which the model is able to explain the data. In this regard, Table 3 displays the marginal density obtained by estimating the model under alternative specifications of this rule. In particular, we consider the case of a constant DTI limit as well as cases in which the DTI limit endogenously react to house prices, household debt and output separately, or in combination of two of them. By and large, the exercise unveils that our baseline model fits data in a superior way.

Table 2: Prior distributions and posterior estimates of parameters and shocks of our DSGE model

Parameter		Prior [mean, std]	Posterior Mean	Posterior Mode	Posterior 10%	Posterior 90%
ε_c	habit in cons.	B $[0.7, 0.1]$	0.360	0.315	0.288	0.429
ε_h	habit in housing	B $[0.7, 0.1]$	0.779	0.728	0.681	0.880
ϕ	inv. adj. cost	G $[5, 2]$	4.730	5.017	3.363	6.045
σ	wage share, borrowers	B $[0.333, 0.20]$	0.081	0.062	0.005	0.159
ψ_b	DTI limit: household debt	N $[0.0, 1.0]$	0.579	0.688	0.398	0.724
ψ_q	DTI limit: house prices	N $[0.0, 1.0]$	2.150	2.074	1.287	2.922
r_r	inertial Taylor rule	B $[0.75, 0.10]$	0.391	0.355	0.309	0.480
r_π	infl. response Taylor rule	N $[1.50, 0.25]$	1.392	1.401	1.264	1.516
r_y	output response Taylor rule	N $[0.125, 0.025]$	0.114	0.116	0.100	0.126
μ_π	Calvo parameter, prices	B $[0.50, 0.075]$	0.937	0.938	0.915	0.958
μ_w	Calvo parameter, wages	B $[0.50, 0.075]$	0.915	0.911	0.899	0.933
γ	inertia borrowing constraint	B $[0.75, 0.10]$	0.490	0.488	0.357	0.612
ρ_j	AR(1) housing shock	B $[0.75, 0.10]$	0.983	0.986	0.973	0.994
ρ_k	AR(1) investment shock	B $[0.75, 0.10]$	0.639	0.630	0.571	0.708
ρ_r	AR(1) monetary shock	B $[0.50, 0.10]$	0.451	0.462	0.385	0.534
ρ_z	AR(1) intertemporal shock	B $[0.75, 0.10]$	0.823	0.820	0.810	0.834
ρ_θ	persistence DTI limit	B $[0.75, 0.10]$	0.711	0.723	0.698	0.746
σ_j	std. housing demand shock	IG $[0.01, 1]$	0.0425	0.0431	0.0238	0.0604
σ_p	std. price markup shock	IG $[0.01, 1]$	0.0037	0.0036	0.0033	0.0041
σ_k	std. investment shock	IG $[0.01, 1]$	0.0353	0.0351	0.0313	0.0391
σ_r	std. int. rate shock	IG $[0.01, 1]$	0.0025	0.0025	0.0023	0.0029
σ_w	std. wage markup shock	IG $[0.01, 1]$	0.0079	0.0080	0.0070	0.0088
σ_z	std. intertemporal shock	IG $[0.01, 1]$	0.0153	0.0149	0.0128	0.0176

Note: Prior distributions: B = Beta; N = Normal; G = Gamma; IG = Inverse Gamma.

2.6 The role of financial amplification mechanisms

A key finding of our Bayesian estimation is that the DTI limit positively co-moved with house prices and the overall level of household debt, so that changes in the DTI limit amplified the borrowing cycle. Noticeably, this effect is warranted by the endogeneity of the DTI limit embedded in our model.

The exercise displayed in Figure 1 sheds further the light on the role played by the rule for the DTI limit in the propagation of structural shocks. We plot the impulse response functions of the household debt-to-output ratio in our estimated model (circled line) and under alternative characterizations of this rule, with all parameters being calibrated at the posterior mean. We consider three different cases. The first one is obtained by setting $\psi_b = 0$ in the rule for the DTI limit (solid line) and implies

Table 3: Model fit: alternative specifications of the rule for the DTI limit

Model version (rule for the DTI limit)	Marginal density
Baseline: $\log(\theta_t) = (1-\rho_\theta)\log(\theta) + \rho_\theta(\psi_q \log(q_t/q) + \psi_b \log(b'_t/b'))$	2427.42
$\log(\theta_t) = (1-\rho_\theta)\log(\theta) + \rho_\theta(\psi_q \log(q_t/q) + \psi_y \log(y_t/y))$	2406.04
$\log(\theta_t) = (1-\rho_\theta)\log(\theta) + \rho_\theta(\psi_b \log(b'_t/b') + \psi_y \log(y_t/y))$	2405.29
$\log(\theta_t) = (1-\rho_\theta)\log(\theta) + \rho_\theta(\psi_b \log(b'_t/b'))$	2403.70
$\log(\theta_t) = (1-\rho_\theta)\log(\theta) + \rho_\theta(\psi_y \log(y_t/y))$	2402.79
$\log(\theta_t) = (1-\rho_\theta)\log(\theta) + \rho_\theta(\psi_q \log(q_t/q))$	2402.36
Constant DTI limit ($\theta_t = \theta$)	2397.78

Note: The table reports the marginal density (computed through Laplace approximation) under different model specifications.

that the DTI limit can only loosen because of increases in house prices. The second case entails $\psi_q = 0$ (dotted line), so that the DTI limit depends only on household debt and there is no direct impact of house prices on the DTI limit. Finally, the case in which the DTI limit is constant ($\theta_t = \theta$) indicates that there is no propagation effect at all through the relaxation of the DTI limit.

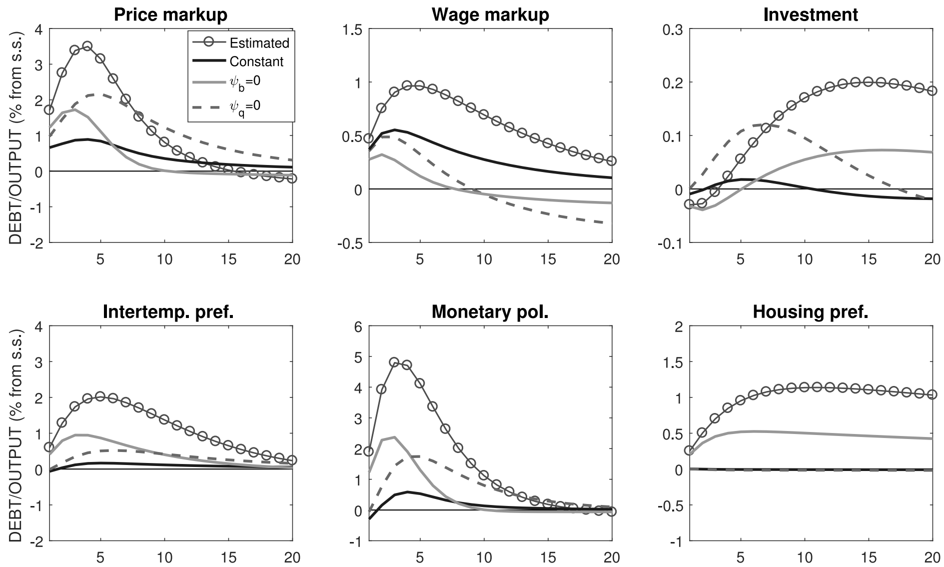
It turns out that the debt-to-output ratio increases to a larger extent in the estimated model whatever is the source of the shock. This is a consequence of the interplay of all the financial amplification mechanisms previously discussed, which reinforce each other fuelling the credit boom. In contrast, when some (either $\psi_b = 0$ or $\psi_q = 0$) or all (when θ is fixed) propagation channels are shut down the financial amplification mechanisms are substantially dampened, producing a muted increase in the debt-to-output ratio.

Hence, the pivotal role played by the borrowing constraint and the DTI limit in amplifying the transmission of structural shocks to financial variables provides a scope for pursuing financial stability and implementing macroprudential policies. We next discuss the effects of the macroprudential policy of our interest.

3 The interaction between central bank and macroprudential policy

The conduct of the Fed during the period leading up to the 2008 crisis has been largely questioned. In particular, the strategy advocated by former Governor Alan Greenspan and labelled "mopping up after the crash", consisting in leaving the credit boom ending on its own without undertaking any monetary policy action, has been criticized and blamed to be too lax. Consequently, an academic debate has focused on how monetary policy should be conducted when the credit boom poses a plausible threat. On one hand, many commentators suggest that the central bank should adopt a "reactive" stance, namely raising interest rate in case of a credit boom.

Figure 1: The role of the endogeneity of the DTI limit in the financial amplification mechanisms



Note: Impulse response function of the ratio between household debt and output to a price markup shock, a wage markup shock, an investment shock, an intertemporal preference shock, a monetary policy shock and a housing preference shock. All shocks are normalized such that the standard deviation of all the shock process increases by 1%. Variables are expressed in percentage variation from the steady state (quarters are reported on the x-axis). The "estimated" model features the rule: $\log(\theta_t) = (1 - \rho_\theta)\theta + \rho_\theta(\psi_q \log(q_t/q) +$ $+ \psi_b \log(b'_t/b'))$. Other cases are obtained by setting $\psi_q = 0$ and $\psi_b = 0$ in this equilibrium condition. The case "constant" DTI limit is given by $\theta_t = \theta$. All other parameters are set at the posterior mean.

This strategy of "leaning against the wind" presumes that a central bank is able to pursue both the goals of inflation targeting and financial stability. On the other hand, an alternative view reckons that the central bank should only pursue its primary objective of stabilizing inflation and output, leaving the goal of financial stability to a macroprudential authority ("two instruments for two goals"). By this virtue the macroprudential authority should be in charge of adopting ex-ante measures with the precise intention of preventing the credit boom.

Our monetary DSGE model offers a comparison between these two cases. To do this, we define specific policy objectives, assuming that central bank and macroprudential authority are two separate entities with clearly-established policy goals. Following an approach commonly adopted in the literature (e.g. Angelini et al., 2014; Darracq Paries et al., 2011) we specify ad-hoc loss functions for both authorities.

3.1 Monetary policy to attain financial stability: "leaning against the wind" policy

In principle, central bank is concerned about minimizing deviations of output and inflation. These standard objectives of monetary policy can be represented by the following loss function:

$$L^{mp} = \sigma_\pi^2 + k_{y,mp}\sigma_y^2 + k_r\sigma_{\Delta R}^2, \qquad k_{y,mp} \geq 0, k_r \geq 0, \tag{18}$$

where $\sigma_\pi^2, \sigma_y^2, \sigma_{\Delta R}^2$ are the asymptotic variances of inflation, output and changes in the interest rate respectively. The presence of the latter in the loss function is justified by the fact that too large changes in the policy rate can be disruptive for the economy, implying that there is a limited territory within which a central bank can steer its monetary policy instruments. The central bank has different preferences over the stabilization of these variables so that assigns different weights $k_{y,mp}$ and k_r. The standard central bank's problem is to minimize the monetary policy loss function L^{mp} by choosing the parameters of its policy rule, i.e. the Taylor rule (16). This problem can be written as:

$$(r_r^\star, r_\pi^\star, r_y^\star) = \operatorname{argmin} L^{mp}(r_r, r_\pi, r_y), \tag{19}$$

where r_r, r_π, r_y are parameters of the Taylor rule.

However, the financial crisis has led many economists to think of the need for central banks to take into account also financial variables – alongside inflation and output – in their decisions concerning the interest rate. In other words, central bank should also be in charge of financial stability. According to this view, when an excess of borrowing threatens the economy the central bank should "lean against the wind" of a credit boom, i.e. raising the interest rate in order to discourage borrowers and thus preserve financial stability.

Consequently, the monetary policy loss function L^{mp} is now complemented with a loss function pertaining to financial stability L^{fs}, so that the total loss function is defined as:

$$L = L^{mp} + L^{fs}. \tag{20}$$

Importantly, we assume that financial stability loss function is given by:

$$L^{fs} = \sigma_{b/y}^2 + k_\theta\sigma_{\Delta\theta}^2, \quad k_\theta \geq 0, \tag{21}$$

where $\sigma_{b/y}^2$ is the variance of household debt as a ratio of output and $\sigma_{\Delta\theta}^2$ is the volatility of the changes in the DTI limit. This latter term is introduced because the policymaker is assumed to perfectly know that the relaxation of the DTI limit leads to an alarming propagation mechanism which may undermine financial stability.

The supplementary policy objective – financial stability – requires a potential interest rate reaction to household debt and house prices. Thus, the standard Taylor rule now becomes an "adjusted" Taylor rule:

$$R_t = R_{t-1}^{r_r} R^{(1-r_r)} \left(\frac{\pi_t^A}{\bar{\pi}^A}\right)^{(1-r_r)r_\pi} \left(\frac{y_t}{y}\right)^{(1-r_r)r_y} \left(\frac{b_t'}{b'}\right)^{(1-r_r)r_b} \left(\frac{q_t}{q}\right)^{(1-r_r)r_q} e_t \,, \tag{22}$$

i.e. the standard Taylor rule is augmented with a reaction to the deviation of household debt and house prices from the steady state, with $r_b, r_q \geq 0$. With the new targets in place, the problem of the central bank becomes:

$$(r_r^\star, r_\pi^\star, r_y^\star, r_b^\star, r_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, r_b, r_q), \tag{23}$$

where the loss function to be minimized is the total one (L).

3.2 Macroprudential DTI limit and "two instruments for two goals"

Generally speaking, a macroprudential policy should react against the financial cycles in order "to avoid the type of boom and bust cycles in the supply of credit and liquidity that has marked the recent financial crisis" (Bank of England, 2009). In practice, this implies that the macroprudential authority should explicitly target financial variables, setting specific instruments in a countercyclical way in order to smooth credit cycles. Recent empirical evidence has documented that a countercyclical DTI limit is effective in restricting the amount of loans that can be requested, facilitating greater resilience of households and lower probability of default (Kuttner and Shim, 2016; IMF, 2013; Jacome and Mitra, 2015; Lim at al., 2011; Vandenbussche et al. 2012). In our framework we assume that the macroprudential authority uses the DTI limit to minimize the financial stability loss function L^{fs}. To achieve this, the macroprudential authority is empowered to set the DTI limit θ_t in a *countercyclical* way. Technically, this means that the parameters ψ_b and ψ_q are assumed to be non-positive:

$$\psi_b \leq 0, \quad \psi_q \leq 0, \tag{24}$$

so as to (potentially) entail a countercylical response to financial variables, like household debt and house prices. Along these lines, an increase of household debt or house prices above their steady state might be tackled by a reduction of the DTI limit below 40%, which is the calibrated steady state value.
Therefore, assuming that the macroprudential authority acts in cooperation with the central bank the problem of joint optimization reads:

$$(r_r^\star, r_\pi^\star, r_y^\star, \rho_\theta^\star, \psi_b^\star, \psi_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, \rho_\theta, \psi_b, \psi_q), \tag{25}$$

where the total loss function L is given by (20). Since the central bank targets standard monetary policy objectives (L^{mp}) by steering the interest rate and the macroprudential authority sets the DTI limit to attain financial stability (L^{fs}), this case can be referred to as the "two instruments for two goals" strategy (Smets, 2014). The "two instruments for two goals" constitutes a cooperative strategy, as the two authorities are assumed to perfectly coordinate to achieve the most efficient (total) outcome. An important caveat is that the case of perfect cooperation between central bank and macroprudential authority is not the only possible in practice. However, we decide to report only results under this regime for essentially two reasons. First, the cooperation central bank-macroprudential authority permits a comparison between the "leaning against the wind" policy pursued by the central bank and the case in which the central bank's standard policy is complemented with a macroprudential authority steering the DTI limit. Second, the extant literature has shown that cooperation generally outperforms non-cooperation, both when the non-cooperative game delivers a Nash equilibrium and when one authority acts as "leader" (optimizing first), whereas the other is "the follower" (Cecchetti and Kohler, 2014; Smets, 2014; Angelini et al., 2014; De Paoli and Paustian, 2017). Since we are interested in the most efficient interaction between the central bank and the macroprudential authority, in the sequel we only discuss the case of perfect cooperation.

3.3 Stabilization effect: policy comparison

In this section we lay out the results of main exercise of analysis, which aims to assess the interaction between monetary and macroprudential policy. We evaluate the performance of different policy regimes based on the ad-hoc loss functions previously described. In order to minimize the loss functions we set up grids of plausible values of the parameters to be optimized, ensuring that the equilibrium is always determinate. We consider the grid $[0.01; 0.99]$ for r_r, $[1.01; 50.00]$ for r_π, $[0.00; 10.00]$ for r_y, $[0.00; 50.00]$ for r_b and r_q. As for the macroprudential policy, grids are set as $[0.01; 0.99]$ for ρ_θ, $[-10.00; 0.00]$ for ψ_b and ψ_q. Table 4 contains the results of this exercise. The first row displays the standard deviations (in percentage points) of target variables and loss functions in our estimated model, that is where parameters are not optimized and all parameters are calibrated at the posterior mean.

It can be seen that a larger fraction of the total loss function is accounted for by the financial stability loss function (L_{fs}), as the ratio between household debt and output increases substantially relative to the estimated model. Moreover, the notable increase in the volatility of the DTI limit implies that financial amplification effects play a significant role.

We can now turn to the optimized reaction of the policymakers. The first row of Table 4 shows the results for the case in which the central bank minimizes its loss function (L_{mp}) and the macroprudential policy is absent, so that parameters in the DTI rule ψ_b and ψ_q are the posterior mean ($\psi_b = 0.579$ and $\psi_q = 2.150$). As expected, standard monetary policy stabilization brings about a marked reduction in the monetary policy loss function. This is attained by a pronounced reaction of the central bank, which steers the interest rate to stabilise output and inflation: indeed, the volatility of the policy rate more than doubles, while output standard deviation is noticeably reduced. Importantly, when central bank only focuses on its standard goal (minimizing L^{mp}) financial stability remains a threat, as the variability of $\sigma^2_{b/y}$ increases.

The case in which the central bank targets also financial stability is reported on the second row of Table 4. It emerges that the policy of "leaning against the wind" leads to a remarkable reduction in debt volatility and thus in the financial stability loss function L^{fs}. However, output and inflation deviate to a larger extent implying that the implementation of the "leaning against the wind" policy generates a trade-off between stabilization of financial variables and stabilization of output and inflation. The small reduction of the total loss function, nonetheless, signals that a central bank's reaction to financial variables is somewhat desirable, in spite of greater variability of output and inflation.

Table 4: Volatility of target variables and loss functions, and values of optimized parameters

	Volatility of target variables					Loss functions		
	π	Y	ΔR	b/y	$\Delta\theta$	L^{mp}	L^{fs}	L
Estimated	0.526	2.184	0.149	39.465	6.998	0.027	7.836	7.863
Only monetary policy	0.573	0.153	0.307	39.489	6.729	0.003	7.842	7.845
Adjusted Taylor rule	3.407	16.972	0.392	25.176	4.007	3.185	1.556	4.742
Only macropr.	0.560	0.694	0.198	0.448	0.955	0.116	0.010	0.126
Macroprud. + mon. pol.	0.565	0.135	0.322	0.383	0.899	0.003	0.001	0.004
Macroprud. + adj. Taylor rule	0.565	0.135	0.322	0.383	0.899	0.003	0.001	0.004

	Optimal coefficients
Only monetary policy	$r_r^\star = 0.86,\, r_y^\star = 5.22, r_\pi^\star = 13.32$
Adjusted Taylor rule	$r_r^\star = 0.84,\, r_y^\star = 1.05, r_\pi^\star = 37.77, r_b^\star = 0.00, r_q^\star = 21.43$
Only macroprudential	$\rho_\theta^\star = 0.74,\, \psi_q^\star = 0.00,\, \psi_b^\star = -6.67$
Macroprud. + mon. pol.	$r_r^\star = 0.80,\, r_y^\star = 5.07, r_\pi^\star = 11.94,\, \rho_\theta^\star = 0.74,$ $\psi_q^\star = 0.00,\, \psi_b^\star = -6.67$
Macroprud. + adj. Taylor rule	$r_r^\star = 0.80,\, r_y^\star = 5.07, r_\pi^\star = 11.94,\, r_b^\star = 0.00, r_q^\star = 0.00,$ $\rho_\theta^\star = 0.74,\, \psi_q^\star = 0.00,\, \psi_b^\star = -6.67$

Note: Variables in the upper panel are expressed in percentage points. Policy regimes:
"Only monetary policy": $(r_r^\star, r_\pi^\star, r_y^\star) = \text{argmin}\, L^{mp}(r_r, r_\pi, r_y)$.
"Only macroprudential policy": $(\rho_\theta^\star, \psi_b^\star, \psi_q^\star) = \text{argmin}\, L^{fs}(\rho_\theta, \psi_b, \psi_q)$.
"Adjusted Taylor rule" : $(r_r^\star, r_\pi^\star, r_y^\star, r_b^\star, r_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, r_b, r_q)$.
"Macroprudential + mon. pol.": $(r_r^\star, r_\pi^\star, r_y^\star, \rho_\theta^\star, \psi_b^\star, \psi_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, \rho_\theta, \psi_b, \psi_q)$.
"Macroprudential+adj. Taylor Rule": $(r_r^\star, r_\pi^\star, r_y^\star, r_b^\star, r_q^\star \rho_\theta^\star, \psi_b^\star, \psi_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, r_b, r_q, \rho_\theta, \psi_b, \psi_q)$.

A much larger decrease in the total loss function is, instead, obtained when monetary policy is complemented with an optimized macroprudential DTI limit (fourth row in Table 4). In this case the macroprudential authority puts in place a strong countercylical response to household debt ($\psi_b^\star = -6.67$) and fully neutralizes the financial amplification mechanism working through real estate prices ($\psi_q^\star = 0.00$). Most noticeably, in this case no trade-off between financial stability and standard monetary policy goals seems to arise: both loss functions decline, denoting a Pareto improvement. Hence, the strategy "two instruments for two goals" markedly

outperforms the “leaning against the wind”.
In principle, this result should not appear surprising, as optimizing an extra policy instrument (the DTI limit) is likely to yield more efficient policy outcomes. However, we now discuss the results of a further exercise which allows to investigate the role of the macroprudential DTI limit as an exclusive policy instrument. Specifically, third row of Table 4 displays the case in which the macroprudential authority minimizes the financial stability loss function L^{fs} given the estimated monetary policy rule. In this case there is only one policy instrument to be optimized – i.e. the DTI limit – as the interest rate follows the estimated Taylor rule. It emerges that the macroprudential DTI limit delivers a stabilization of the economy that is more effective than the “leaning against the wind” policy: indeed, the macroprudential DTI limit produces an evident Pareto improvement, as both loss functions L^{mp} and L^{fs} are relatively smaller. Hence, a compelling result of the analysis is that the macroprudential DTI limit is, by itself (i.e. for a given monetary policy), a more efficient policy outcome than the “leaning against the wind” policy because improves the trade-off between financial stability and monetary policy.
Finally, we also find that complementing the “two instruments for two goals” strategy with a central bank’s reaction to credit growth and house prices turns out to be unprofitable, because the combination between “two instruments for two goals” and “leaning against the wind” does not produce any further improvement in terms of stabilization of the economy with respect to the “two instruments for two goals” policy. To see this, last row in Table 4 exhibits the case in which the “two instruments for two goals” policy is augmented with a central bank’s reaction to household debt and house prices. The result is that the optimized central bank’s response to these variables is null ($r_b^\star = 0.00$, $r_q^\star = 0.00$), implying that that any central bank’s response to financial variables is sub-optimal when the “two instruments for two strategy” is in place.
To sum up, the exercise has shown that “leaning against the wind” is a sub-optimal policy that falls short of the strategy “two instruments for two goals” in achieving an efficient policy outcome. Put differently, the standard conduct of monetary policy is significantly improved when complemented with a macroprudential DTI limit in a coordinated “two instruments for two goals” strategy, which makes any potential central bank’s reaction to financial variables unnecessary. To understand why the macroprudential DTI limit is a desirable complement of monetary policy we next delve into the dynamics of the model.

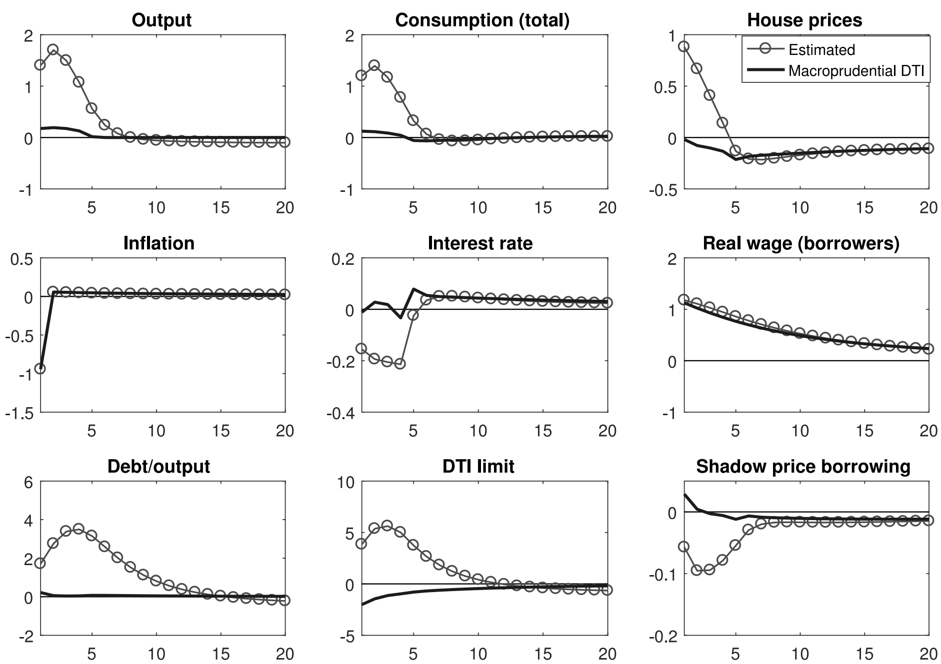
4 Inspecting the dynamics: the role of the macroprudential DTI limit

In order to investigate more in depth the stabilization effect of the cooperation between monetary and macroprudential policy we analyse the dynamics of the model, both when the macroprudential policy is absent and when instead is active and optimized. This experiment provides further evidence of the role played by the DTI limit in exacerbating the credit boom and the positive effect of macroprudential authority seeking to dampen harmful propagation mechanisms.

4.1 Supply shocks

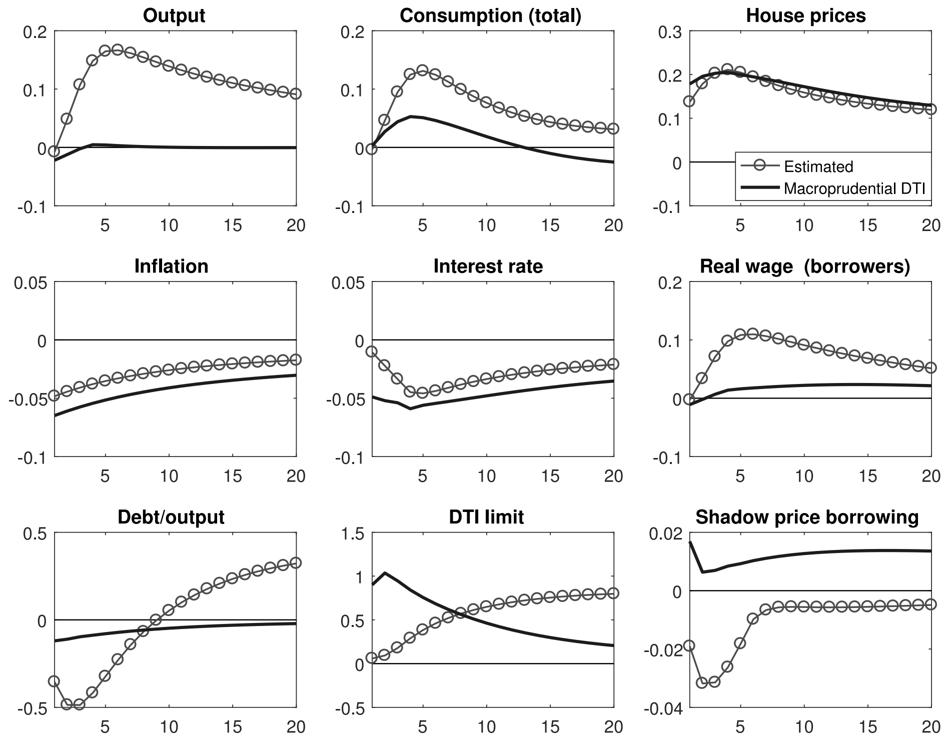
Figures 2–3 display the impulse response functions to a 1% unexpected *decrease* of the price markup (Figure 2) and the wage markup (Figure 3).

Figure 2: Price markup shock



Note: Impulse response functions of main variables to a 1% price markup shock $u_{p,t}$. Variables are expressed in percentage variation from the steady state (quarters are reported on the x-axis). "Macroprudential DTI": $\rho_\theta^\star = 0.74$, $\psi_q^\star = 0.00$, $\psi_b^\star = -6.67$, whereas all other parameters are set at the posterior mean.

Figure 3: Wage markup shock



In the estimated model (circled lines) the supply shock produces an increase in output and a reduction of inflation. As a consequence, the standard Taylor rule entails a cut of the policy rate, which remains at a lower rate with some degree of inertia. A lower interest rates reduces the present value of debt (i.e. the standard borrowers' balance-sheet channel) making new debt cheaper for borrowers. However, in our model a reduction of the policy rate gives rise to two further amplification mechanisms that complement and reinforce each other fuelling the credit boom. The first mechanism operates through an appreciation of the collateral, which in our model is borrowers' labor income. A reduction of the policy rate slowly boosts borrowers' labor income which in turn leads borrowers to request a greater amount of debt as in the standard transmission a' la Kiyotaki and Moore (1997). Instead, the second amplification stems from the increase in house prices. More specifically, an interest rate cut drives up house prices as often discussed in the literature (see, among the others, Iacoviello and Neri, 2010). The house prices increase successively feeds through to household debt via a relaxation of the DTI limit. In other words, the endogenous rule for the DTI limit generates a positive comovement between house prices and DTI limit which ultimately translates into a marked increase in household borrowing through the rise of the DTI limit in the borrowing constraint. In both mechanisms the increase in household debt then propagates to additional leverage by means of the dependence of the DTI limit to household debt ($\log(b'_t/b)$), through a sort of amplification “loop”. Mirror image of the interplay of these two financial amplification mechanisms is the behaviour of the Lagrange multiplier associated to the borrowing constraint. This variable is a measure of the “shadow” price of borrowing so that an increase (decrease) indicates that the borrowing constraint is more (less) tightening. In the estimated model an increase in credit availability – spurred by a shock that enhances borrowers' labor income and house prices – reflects into a reduction of the shadow price of borrowing: intuitively, with an higher DTI limit debt becomes more accessible at the margin.

When the macroprudential DTI limit is active the dynamics of the main variables changes significantly. The solid lines in Figures 2–3 depict the cases in which the macroprudential DTI limit is optimized, so that parameters of the DTI rule (6) are set as $\rho^\star_\theta = 0.74$, $\psi^\star_q = 0.00$, $\psi^\star_b = -6.67$ while all other parameters are kept at their posterior mean. The pattern is now strikingly different: in spite of the same increase in labor income the ratio between household debt and output remains quite stable. This is a clear consequence of the countercyclical movement of the DTI limit, which is reduced so as to mitigate the financial amplification channels.

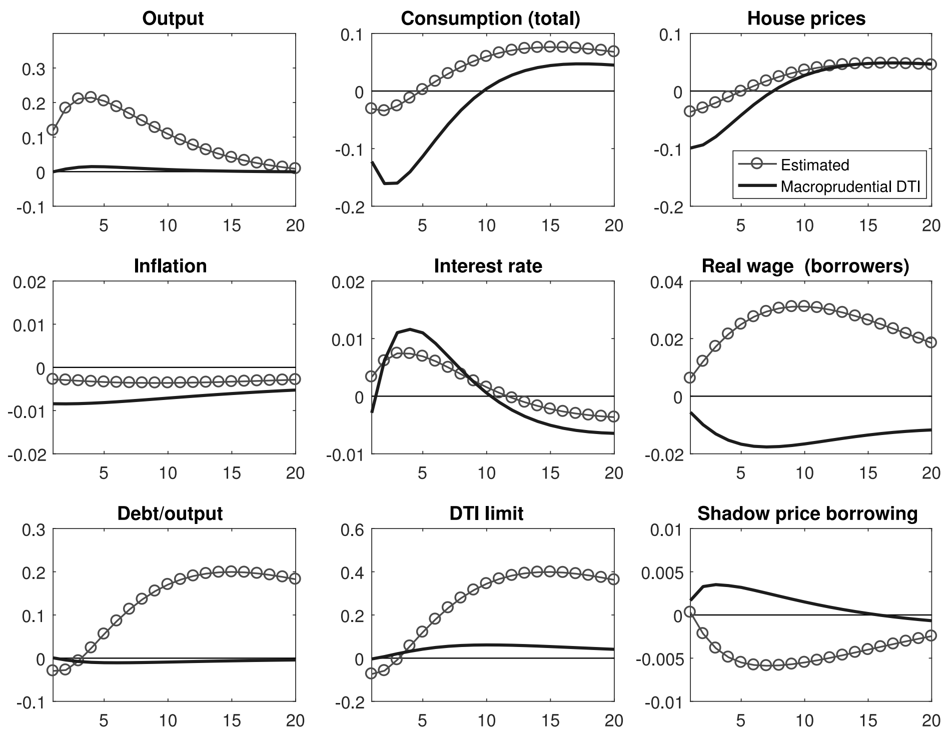
An additional effect of the implementation of the macroprudential DTI limit is that the change of the shadow price of borrowing now shows a different sign: an increase in the shadow price of borrowing entails that requesting more debt is now more “costly”. A subtle interpretation therefore arises: with the macroprudential DTI in place a particular trade-off seems to appear, as greater financial stability (namely, smaller deviation of the household debt-to-output ratio) is obtained at the cost of a larger increase of the shadow price of borrowing, that constitutes a “wedge” in the economy.

4.2 Demand shocks

Figures 4–5 plot the impulse response functions obtained by simulating demand shocks, that is a 1% investment shock (Figure 4) and a 1% intertemporal preference shock (Figure 5).

In contrast to supply shocks these do not generate a decrease in inflation, so that the policy rate is not lowered. Therefore, rather than interest rate cuts (as in supply shocks) financial amplification mechanisms are now triggered by increases in aggregate demand, which boost production and, consequently, hours worked. The implied rise of borrowers' labor income fuels household debt via the borrowing constraint and, as in the case of supply shocks, the decline in the shadow price of borrowing signifies that the borrowing constraint is relatively less stringent. The increase in household debt generates in turn an additional propagation mechanism according to which household debt builds up endogenously, owing to the amplification “loop” driven by the presence of $\log(b'_t/b)$ in the rule for the DTI limit.

Figure 4: Investment shock



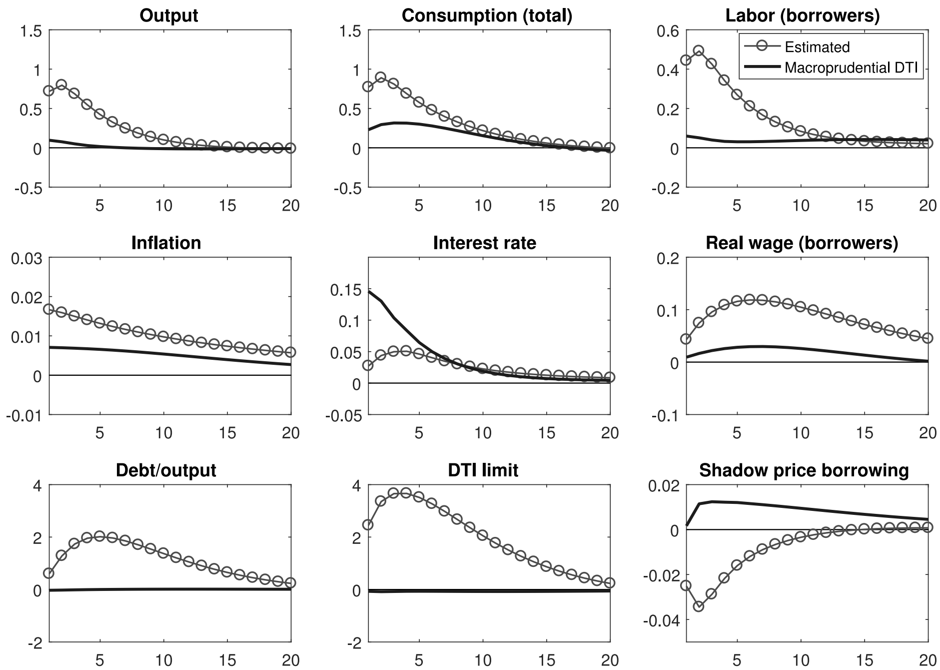
On the other hand, the macroprudential DTI limit is, again, largely effective: the countercyclical steering of the DTI limit (which entails a tightening of the borrowing constraint, i.e. an increase in the shadow price of borrowing) brings about an effective stabilization of the ratio between household debt and output, which remain very close to the trend.

4.3 Housing demand shock

As widely documented in the literature, an housing preference shock (Figure 6) leads to an immediate appreciation of real estate values, while the impact on consumption and output remains quite subdued. The strong increase in house prices relaxes the constraint and triggers household borrowing leading to a significant rise in the household debt-to-output ratio.

The financial amplification mechanism is, however, novel. In the literature, an increase in the appetite for housing pushes up house prices, generating a rise of household debt via the appreciation of the collateral (Iacoviello, 2005; Iacoviello and Neri, 2010). In

Figure 5: Intertemporal preference shock



our model the final effect is the same, but the transmission is different: the house prices increase is related to a relaxation of the DTI limit which, through the second-round effect on debt (i.e. the "loop" via $\log(b_t'/b)$ previously described) ultimately turns into higher credit supply.

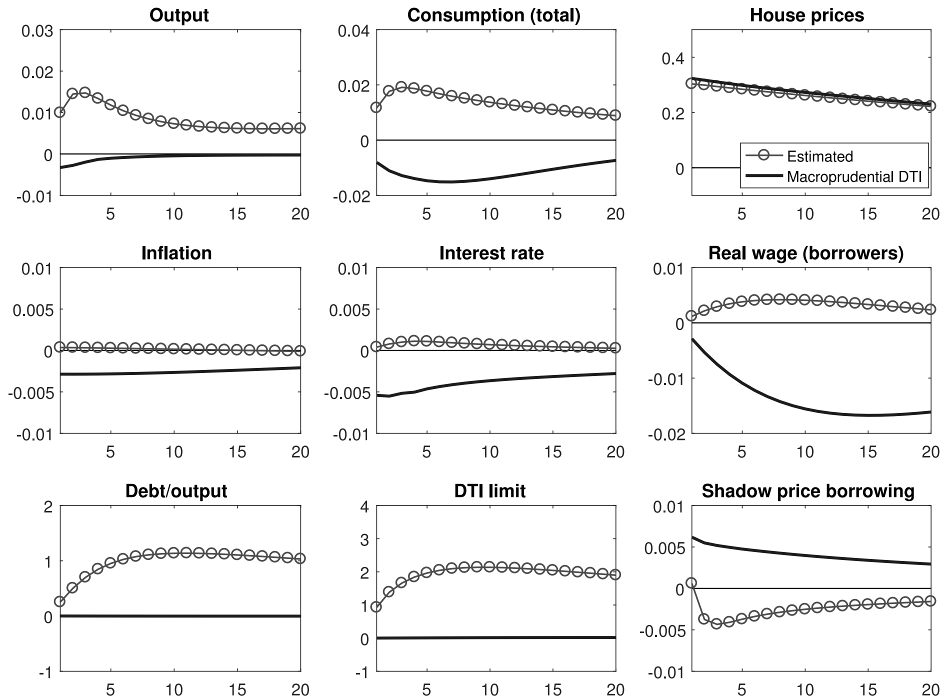
Once again, the implementation of the macroprudential policy is able to dampen this financial amplification mechanism and to prevent an excessive accumulation of household debt, so that financial stability is successfully achieved.

4.4 Counterfactual exercise

As a further experiment, we simulate the model using the series of supply, demand and housing shocks extracted through the Kalman smoother. In this fashion, the effects of the macroprudential policy are analysed with respect to a continuous flow of structural shocks hitting at the same time and potentially having different sign.

Figure 7 displays the responses of two policy regimes: the case in which central bank is seeking to stabilize the economy without the support of the macroprudential policy and the case of the cooperation monetary-macroprudential policy, where this latter is configured as a countercyclical DTI limit.

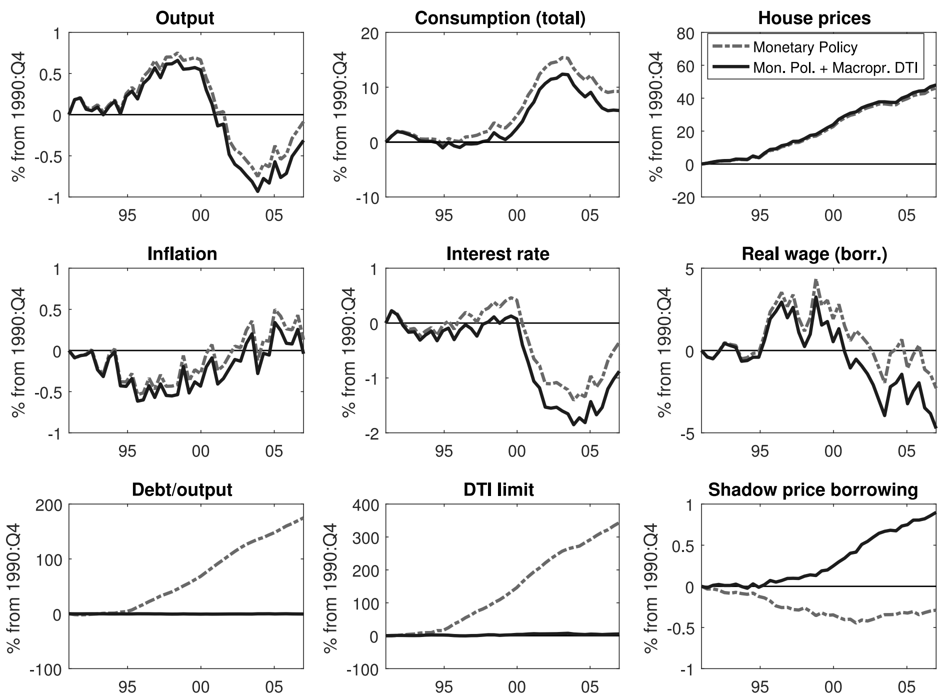
Figure 6: Housing demand shock



We express the variables as difference with the respect to the value observed in 1990:Q4. It can be seen that in both cases house prices increase dramatically from 1996 through 2005. However, the DTI limit responds in a completely different way in the two regimes. In fact, when the policymaker is only involved in standard monetary policy objectives the DTI limit loosens considerably, fostering the credit boom. The ratio between household debt and output soars by almost 200%, a value that is overall consistent with the build-up of leverage observed in the data. Once more, the decrease of the shadow price of borrowing implies that, at the margin, the borrowing constraint becomes less binding, so that borrowers are induced to borrow to a larger extent.

By sharp contrast, in the case when a macroprudential DTI is implemented the household debt-to-output ratio remains exceptionally stable, in spite of the same increase in house prices. The remarkable stabilization of household debt occurs because amplification mechanisms are dampened by the optimized response of the macroprudential authority, which fully disentangles the DTI limit from house prices (i.e. $\psi_q^\star = 0.00$) and reacts to household debt in a countercyclical way ($\psi_b^\star = -6.67$). Now the shadow price of borrowing goes up steadily, signalling a progressive tightening of the borrowing constraint.

Figure 7: Smoothed shocks: counterfactual exercise



Note: Responses of the main model variables, under the sequence of smoothed shocks $u_{p,t}, u_{w,t}, u_{k,t}, z_t, j_t$. Variables are expressed in percentage variation from the steady state and reported as difference with respect to the level in 1990:Q4 (quarters are reported on the x-axis). Policy regimes: "Monetary policy": $r_r^\star = 0.86$, $r_y^\star = 5.22, r_\pi^\star = 13.32$; "Mon. pol. + macroprudential DTI": $r_r^\star = 0.80$, $r_y^\star = 5.07, r_\pi^\star = 11.94$, $\rho_\theta^\star = 0.74$, $\psi_q^\star = 0.00$, $\psi_b^\star = -6.67$. In both policy regimes all other parameters are set at the posterior mean.

The impulse response functions of other variables instead reveal the extent to which the implementation of the macroprudential DTI affects the real economy. By and large, the countercylical DTI limit entails that output and consumption increases to a smaller degree throughout, leading to lower inflation levels and thus a more accommodative monetary policy. Therefore, an interesting result of the analysis is that had a macroprudential DTI limit been optimally implemented during the period 1995–2006 the policy rate would have been (slightly) lower than the level implied by an optimized Taylor rule.

5 Robustness

5.1 Alternative parametrization loss functions

In this section we investigate the extent to which results hinge on the values assigned to the weights in the loss functions. As in Angelini et al. (2014) we have assumed that financial stability loss function does not encompass a response to output changes, i.e. $k_{y,fs} = 0$. Table 5 shows that results are substantially robust when output stabilization is attached a larger weight, that is when $k_{y,fs}$ is equal to 0.1 or 0.5. In both cases, the cooperation between central bank and macroprudential authority produces a clear Pareto improvement with respect to all other regimes. Importantly, these results are also robust to different weights to changes in the DTI limit in the financial stability loss function (k_θ) as well as output stabilization in the monetary policy loss function ($k_{y,mp}$).

Table 5: Robustness: different parametrization of $k_{y,mp}, k_{y,fs}, k_\theta$

	L^{mp}	L^{fs}	L	L^{mp}	L^{fs}	L
	$k_{y,mp} = 0.05$			$k_{y,mp} = 1$		
Estimated	0.0049	7.9408	7.9457	0.0468	7.9408	7.9877
Only monetary policy	0.0031	7.8074	7.8105	0.0036	7.7950	7.7985
Adj. Taylor Rule	1.2993	0.6994	1.9987	1.1236	4.8693	5.9929
Only macroprudential	0.0034	0.0005	0.0039	0.0080	0.0005	0.0085
Macroprudential + mon. pol.	0.0031	0.0003	0.0034	0.0034	0.0001	0.0035
	$k_{y,fs} = 0.1$			$k_{y,fs} = 0.5$		
Estimated	0.0247	7.9453	9.9700	0.0247	7.9629	7.9877
Only monetary policy	0.0035	7.7975	7.8010	0.0035	7.7976	7.8011
Adj. Taylor Rule	0.5861	4.7356	5.3217	0.5877	5.4052	5.9929
Only macroprudential	0.0056	0.0009	0.0065	0.0056	0.0029	0.0085
Macroprudential + mon. pol.	0.0034	0.0001	0.0035	0.0034	0.0001	0.0035
	$k_\theta = 0.0$			$k_\theta = 0.5$		
Estimated	0.0247	7.8838	7.9085	0.0247	8.1692	8.1939
Only monetary policy	0.0035	7.7971	7.8006	0.0035	7.9993	7.8028
Debt-adj. Taylor Rule	2.2840	2.4126	4.6966	2.2840	2.4132	4.6972
Only macroprudential	0.0056	0.0004	0.0060	0.0056	0.0006	0.0062
Macroprudential + mon. pol.	0.0034	0.0001	0.0035	0.0034	0.0002	0.0036

Note: The table reports loss functions (in percentage points), defined in Section 3. Policy regimes:
"Only monetary policy": $(r_r^\star, r_\pi^\star, r_y^\star) = \text{argmin}\, L^{mp}(r_r, r_\pi, r_y)$.
"Only macroprudential policy": $(\rho_\theta^\star, \psi_b^\star, \psi_q^\star) = \text{argmin}\, L^{fs}(\rho_\theta, \psi_b, \psi_q)$.
"Adjusted Taylor rule" : $(r_r^\star, r_\pi^\star, r_y^\star, r_b^\star, r_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, r_b, r_q)$.
"Macroprudential + mon. pol.": $(r_r^\star, r_\pi^\star, r_y^\star, \rho_\theta^\star, \psi_b^\star, \psi_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, \rho_\theta, \psi_b, \psi_q)$.

5.2 Alternative steady state values of the DTI limit

The steady state value of the DTI limit is being calibrated by referring to previous literature (e.g. Mendoza, 2002). Our simulations have then shown that the DTI limit loosenes to a very large extent, increasing significantly from the 40% value. In this regard, Figure 7 displays that the DTI limit has more than tripled in the period 1995–2006. As largely discussed, this strong amplification mechanism justifies the implementation of a macroprudential DTI limit with the purpose of stabilizing household debt. However, the effectiveness of the macroprudential DTI limit as a stabilization tool might heavily depend on the degree to which the DTI limit is allowed to relax during the credit boom phase. Intuitively, a higher level of the DTI limit in the steady state implies that a given shock sequence would produce a more sizeable increases in household debt, calling for a stronger action of the macroprudential authority. To show that this is indeed the case we repeat the simulations and the policy comparison assuming a higher level of the DTI limit in the steady state (60% and 100%). Table 6 shows that when the steady state value of the DTI limit is larger the cooperation central bank-macroprudential authority delivers a macroeconomic stabilization which is relatively more efficient, compared to all other policy regimes. The reason is that the role of the macroprudential authority in dampening financial amplification mechanisms has to strengthen in order to tackle a bigger threat to financial stability.

Table 6: Robustness: different parametrization of the steady state DTI limit (θ)

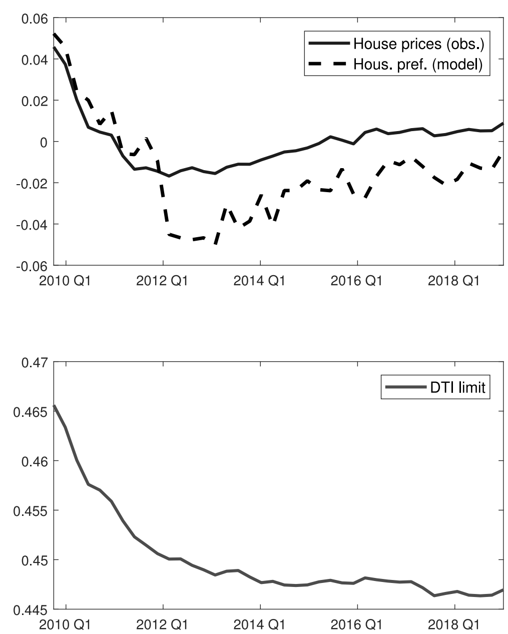
	L^{mp}	L^{fs}	L	L^{mp}	L^{fs}	L
		$\theta = 60\%$			$\theta = 100\%$	
Estimated	0.0260	18.1678	18.1938	0.0295	52.3090	52.3385
Only monetary policy	0.0039	17.8454	17.8493	0.0054	51.6430	51.6483
Adj. Taylor Rule	3.1296	4.7066	7.8362	4.4918	10.0375	14.5293
Only macroprudential	0.0057	0.0011	0.0068	0.0062	0.0030	0.0092
Macropr. DTI + Taylor Rule	0.0036	0.0002	0.0038	0.0041	0.0006	0.0047

Note: The table reports volatility of target variables and loss functions, and values of optimized parameters. Variables are expressed in percentage points. Policy regimes:
"Only monetary policy": $(r_r^\star, r_\pi^\star, r_y^\star) = \text{argmin}\, L^{mp}(r_r, r_\pi, r_y)$.
"Only macroprudential policy": $(\rho_\theta^\star, \psi_b^\star, \psi_q^\star) = \text{argmin}\, L^{fs}(\rho_\theta, \psi_b, \psi_q)$.
"Adjusted Taylor rule" : $(r_r^\star, r_\pi^\star, r_y^\star, r_b^\star, r_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, r_b, r_q)$.
"Macroprudential + mon. pol.": $(r_r^\star, r_\pi^\star, r_y^\star, \rho_\theta^\star, \psi_b^\star, \psi_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, \rho_\theta, \psi_b, \psi_q)$.

6 Out-of-sample analysis: 2009Q4-2019Q4

Results discussed so far are based on a sample which runs until the beginning financial crisis, namely when the credit boom was largely fueled by an appreciation of real estate values. It is nonetheless interesting to perform an out-of-sample experiment in order to evaluate the robustness of the main results as well as provide more discussion points. Therefore, the model is re-estimated over an out-of-sample period and then the optimal policy analysis is performed over the same period. More specifically, the model is estimated over a 2009:Q4–2019:Q4 sample, which contains 41 quarterly observations.

Figure 8: Out-of-sample analysis: 2009Q4-2019Q4 sample



Note: Housing preference shock and housing observable variabe (upper panel), simulated path of the DTI limit under the optimized "two instruments for two goals" policy (lower panel).

This smaller sample has some similarities with the original one, in particular with regards to house prices which display a prolonged and sustained increase in the second half of the sample (see solid line in Figure 8). Also, the new estimation shows that the housing price increase is again driven by the housing demand shock (Figure 8, dashed line). Besides house prices, household debt is also rising to alarming levels (see Federal Reserve Bank of New York, 2021). In this scenario the unprecedented low-rates environment presumably represents a significant driver with respect to the pre-crisis period, where rates were relatively higher. As a consequence, the strong linkage between house prices and credit supply, i.e. the "valuation" view, might not be, in principle, as important as in the pre-crisis credit boom phase, and this would likely lead to different policy recommendations. In this regard, an out-of-sample policy analysis would ultimately indicate the extent to which a macroprudential DTI limit is still an effective policy even in case of looser financial conditions, such as low interest rates.

Table 7: Volatility of target variables and loss functions, and values of optimized parameters

	Optimal coefficients
Only monetary policy	$r_r^\star = 0.87,\ r_y^\star = 2.10, r_\pi^\star = 11.98$
Adjusted Taylor rule	$r_r^\star = 0.91,\ r_y^\star = 2.10, r_\pi^\star = 11.98, r_b^\star = 0.00, r_q^\star = 0.00$
Only macroprudential	$\rho_\theta^\star = 0.91,\ \psi_q^\star = 0.00,\ \psi_b^\star = -1.37$
Macroprud. + mon. pol.	$r_r^\star = 0.82,\ r_y^\star = 1.92, r_\pi^\star = 7.78,\ \rho_\theta^\star = 0.89,$ $\psi_q^\star = 0.00,\ \psi_b^\star = -2.12$
Macroprud. + adj. Taylor Rule	$r_r^\star = 0.82,\ r_y^\star = 1.92, r_\pi^\star = 7.78,\ r_b^\star = 0.00, r_q^\star = 0.00,$ $\rho_\theta^\star = 0.89,\ \psi_q^\star = 0.00,\ \psi_b^\star = -2.12$

Note: Variables are expressed in percentage points. Policy regimes: "Only monetary policy": $(r_r^\star, r_\pi^\star, r_y^\star) = $ $= \text{argmin}\, L^{mp}(r_r, r_\pi, r_y)$. "Only macroprudential policy": $(\rho_\theta^\star, \psi_b^\star, \psi_q^\star) = \text{argmin}\, L^{fs}(\rho_\theta, \psi_b, \psi_q)$. "Adjusted Taylor rule" : $(r_r^\star, r_\pi^\star, r_y^\star, r_b^\star, r_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, r_b, r_q)$. "Macroprudential + mon. pol.": $(r_r^\star, r_\pi^\star, r_y^\star, \rho_\theta^\star, \psi_b^\star, \psi_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, \rho_\theta, \psi_b, \psi_q)$. "Macroprudential + adj. Taylor Rule": $(r_r^\star, r_\pi^\star, r_y^\star, r_b^\star, r_q^\star \rho_\theta^\star, \psi_b^\star, \psi_q^\star) = \text{argmin}\, L(r_r, r_\pi, r_y, r_b, r_q, \rho_\theta, \psi_b, \psi_q)$.

Results of this analysis show that the macroprudential policy is optimal when it is implemented in a coordinated fashion with the monetary authority in a "two instruments for two goals" strategy, but the implied response is now muted ($\psi_b^\star = -2.12$) as less vulnerable financial conditions (namely, low interest rates) do not call for a stronger "prudential" reaction. Interestingly enough, this is also proven by the fact that the optimal macroprudential policy now envisages a more persistent reaction ($\rho_\theta^\star = 0.91$), implying a slow and progressive reduction of the DTI limit over the period considered (lower panel in Figure 8). By sharp contrast, a "leaning against the wind policy" turns out to be even suboptimal compared to the optimized Taylor rule ($r_b^\star = 0.00$), thus corroborating the finding that the central bank ought not to target financial variables.

All in all, this out-of-sample exercise confirms the efficacy of the optimized "two instruments for two goals" in a different monetary policy regime, that is when market rates are historically low.

7 Concluding remarks

The financial crisis has sparked many debates concerning the main causes of the pre-crisis credit boom. To provide a valid account of this story we have considered a monetary DSGE model featuring an income-based borrowing constraint such that the maximum average amount of debt requested is a proportion – the DTI limit – of labor income.

Remarkably, our Bayesian estimation of the model has revealed that an endogenous DTI limit generates a rich dynamics that allows to identify three distinct drivers of the credit boom which presumably acted simultaneously and reinforced each other. The first driver is the exorbitant increase in house prices. The extant literature has documented how the soar in house prices led households to request further debt, aggravating the borrowing cycle. In our model, a strong increase in house prices is associated to a loosening of the DTI limit which allows borrowers to take on more debt. The second driver of the credit boom is the relaxation of credit standards, widely discussed in the literature. A loosening of the DTI limit like the one envisaged by our model is certainly consistent with this story. The third driver is a period of economic expansion, that some empirical papers deems as a key precursor of a credit boom. Our simulations clearly suggest that the combination of supply and demand shocks experienced in the 80's and 90's can be considered a strong forerunner of the boom phase.

On the whole, the joint effect of these driving forces poses a threat to financial stability calling for some implementation of macroprudential policies. In our framework, the macroprudential authority uses the DTI limit in a counterycylical way to smooth the credit cycle so that an excessive growth of household debt is averted and financial stability is successfully safeguarded. Hence, a clear result of the paper is that this macroprudential policy is effectively capable of avoiding a credit boom.

However, from a normative analysis perspective the implementation of a macroprudential policy should not be analysed on its own, but in interaction with the conduct of monetary policy: in fact, a macroprudential policy might clash with monetary policy objectives, for example when financial stability objectives "outweigh" standard monetary policy goals. In other words, a potential trade-off is likely to arise. Our normative analysis shows that perfect cooperation central bank-macroprudential authority in pursuing the "two instruments for two goals" strategy delivers the best policy outcome, as both authorities can more efficiently achieve their goals so that the overall macroeconomic stabilization improves considerably.

In terms of the monetary policy stance the analysis leads to an important conclusion: the implementation of macroprudential DTI limit enhances the effectiveness of monetary policy in stabilizing the economy, insofar as monetary policy actions are governed by the standard Taylor rule. By sharp contrast, a "leaning against the wind" policy whereby central bank takes into account also financial stability is clearly sub-optimal, as the trade-off between standard monetary policy goals and financial

stability worsens substantially, favouring financial stability over standard monetary policy objectives. A combination of "leaning against the wind" and "two instruments for two goals" is instead shown to be unprofitable, because unable to produce any significant improvement with respect to the "two instruments for two goals" strategy. All in all, this study proves that credit standards should be set in a countercyclical way, taking into account borrowers' labor income to a larger extent than before the crisis. Recent trends in macroprudential regulation seem to suggest that this represents a quite plausible way for years to come.
As in the tradition of the monetary DSGE literature the model is simple and tractable with the purpose of drawing clear policy implications. Although the analysis delivers uncontroversial results we are conscious of the fact that there may be limitations as well as possible extensions that might be worth exploring. Firstly, we have abstracted from modelling the financial intermediation sector. The presence of this sector in the model implies that structural shocks have an impact on the economy also through intermediation channels, which would ultimately affect the stabilization effect of the macroprudential policy. Secondly, since in this paper we study the interaction between monetary and macroprudential policy *conditional* on a given path of house prices (namely the one that caused the pre-crisis credit boom) we have safely assumed that housing is in fixed supply. A researcher interested in investigating also the long-run impact of the interaction monetary-macroprudential policy on house prices should also introduce housing investment and production in the model. We leave these issues for future research.

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Appendix A Equilibrium conditions of DSGE model

In this section we lay out a summary of all equilibrium conditions that characterize the competitive equilibrium of our DSGE model.
Given the definition of utility functions for savers

$$z_t\left(\Gamma_c \log(c_t - \varepsilon_c c_{t-1}) + j_t \Gamma_h \log(h_t - \varepsilon_h h_{t-1}) - \frac{1}{1+\eta} n_t^{1+\eta}\right)$$

and borrowers

$$z_t\left(\Gamma_c \log(c'_t - \varepsilon_c c'_{t-1}) + j_t \Gamma_h \log(h'_t - \varepsilon_h h'_{t-1}) - \frac{1}{1+\eta} n_t^{\prime 1+\eta}\right),$$

we define marginal utility of consumption, housing and labor as $u_{c,t}$, $u_{h,t}$, $u_{n,t}$ for savers and $u_{c',t}$, $u_{h',t}$, $u_{n',t}$ for borrowers. Therefore, savers' equilibrium conditions are given by:

$$u_{c,t} = \beta E_t \left[u_{c,t+1} R_t / \pi_{t+1}\right], \tag{A1}$$

$$q_t u_{c,t} = u_{h,t} + \beta E_t \left[q_{t+1} u_{c,t+1}\right], \tag{A2}$$

$$\frac{w_t}{\chi_{w,t}} u_{c,t} = u_{n,t}, \tag{A3}$$

$$k_t = a_t \left(i_t - \frac{\phi}{2}\left(\frac{\Delta i_t^2}{i}\right)\right) + (1-\delta_k) k_{t-1}\ , \tag{A4}$$

$$u_{c,t} q_{k,t} \left(1 - \phi \frac{\Delta i_t}{i}\right) = \beta E_t \left(u_{c,t+1}\left(r_{k,t+1} + q_{k,t+1}\frac{1-\delta_k}{a_{t+1}}\right)\right), \tag{A5}$$

$$u_{c,t} \frac{q_{k,t}}{a_t} = u_{c,t} - \beta E_t \left(u_{c,t+1} q_{k,t+1} \phi \frac{\Delta i_{t+1}}{i}\right). \tag{A6}$$

After imposing the market clearing condition in the asset market ($b_t = b_t'$) borrowers' equilibrium conditions are:

$$c_t' + \Delta q_t h_t' + \frac{R_{t-1} b_{t-1}}{\pi_t} = \frac{w_t' n_t'}{\chi_{w,t}'} + b_t + div_t', \tag{A7}$$

$$div_t' = \frac{\chi_{w',t} - 1}{\chi_{w',t}} w_t' n_t', \tag{A8}$$

$$b_t = \gamma b_{t-1} + (1-\gamma)\theta_t w_t' n_t', \tag{A9}$$

$$(1-\lambda_t) u_{c',t} = \beta' E_t \left(u_{c,t}(R_t - \xi_{t+1})/\pi_{t+1}\right), \tag{A10}$$

$$q_t u_{c',t} = u_{h',t} + \beta' E_t \left[q_{t+1} u_{c',t+1}\right], \tag{A11}$$

$$\frac{w_t'}{\chi_{w',t}} u_{c',t} (1 + \xi_t \theta_t (1-\gamma)) = u_{n',t}, \tag{A12}$$

where ξ_t is the Lagrange multiplier associated to the borrowing constraint, i.e. the "shadow" price of borrowing, normalized by marginal utility $u_{c',t}$.
The endogenous DTI limit is defined as:

$$\log(\theta_t) = (1-\rho_\theta)\log(\theta) + \rho_\theta(\psi_q \log(q_t/q) + \psi_b \log(b_t'/b')). \tag{A13}$$

Aggregate production, supply side conditions and Phillips curves read:

$$y_t = n_t^{(1-\sigma)(1-\alpha)} n_t'^{\sigma(1-\alpha)} k_{t-1}^{\alpha}, \tag{A14}$$

$$(1-\alpha)(1-\sigma) y_t = \chi_{p,t} w_t n_t, \tag{A15}$$

$$(1-\alpha)\sigma y_t = \chi_{p,t} w_t' n_t', \tag{A16}$$

$$\alpha y_t = \chi_{p,t} r_{k,t} k_{t-1}, \tag{A17}$$

$$\log(\pi_t/\bar{\pi}) = \beta E_t \log(\pi_{t+1}/\bar{\pi}) - \varepsilon_\pi \log(\chi_{p,t}/\bar{\chi_p}) + u_{p,t}, \tag{A18}$$

$$\log(\omega_t/\bar{\pi}) = \beta E_t \log(\omega_{t+1}/\bar{\pi}) - \varepsilon_w \log(\chi_{w,t}/\bar{\chi_w}) + u_{w,t}, \tag{A19}$$

$$\log(\omega'_t/\bar{\pi}) = \beta' E_t \log(\omega'_{t+1}/\bar{\pi}) - \varepsilon'_w \log(\chi'_{w,t}/\bar{\chi'_w}) + u_{w,t}, \tag{A20}$$

with $\omega_t = (w_t\pi_t/w_{t-1})$, $\omega'_t = (w'_t\pi_t/w'_{t-1})$, and parameters defined as $\varepsilon_\pi = (1-\mu_\pi)(1-\beta\mu_\pi)/\mu_w$, $\varepsilon'_w = (1-\mu_w)(1-\beta'\mu_w)/\mu_w$.
The standard Taylor rule is:

$$R_t = R_{t-1}^{r_R} R^{(1-r_R)} \left(\frac{\pi_t^A}{\pi^A}\right)^{(1-r_r)r_\pi} \left(\frac{y_t}{y}\right)^{(1-r_R)r_y} e_t. \tag{A21}$$

Market clearing condition in the housing market closes the equilibrium:

$$h_t + h'_t = 1. \tag{A22}$$

Hence, the competitive equilibrium of the DSGE model is given by a set of stochastic processes:

$$\left\{y_t, c_t, c'_t, h_t, h'_t, n_t, n'_t, b_t, \omega_t, \omega'_t, \xi_t, q_t, q_t^k, \pi_t, r_t^k, k_t, i_t, R_t, \chi_{p,t}, \chi_{w,t}, \chi_{w',t}, \theta_t\right\},$$

and exogenous stochastic processes $\{j_t, a_t, e_t, z_t\}_{t=0}^{\infty}$, such that equations (A1)–(A22) are all contemporaneously satisfied.

Appendix B Data, observation equations, variance decomposition of estimated model

We use same time series as in Guerrieri and Iacoviello (2017). Likewise, we apply the one-sided HP filter with smoothing parameters set to 100,000 in order to remove the trend component from raw data.

i) **Consumption**. Real personal consumption expenditure, logged and then detrended with HP filter. Model variable: $\tilde{C}_t = \log(\frac{c_t + c'_t}{c + c'})$.

ii) **Interest rate**. Effective Federal Funds Rate, annualized percent, divided by 400.
Model variable: $\tilde{r_t} = R_t - 1$.

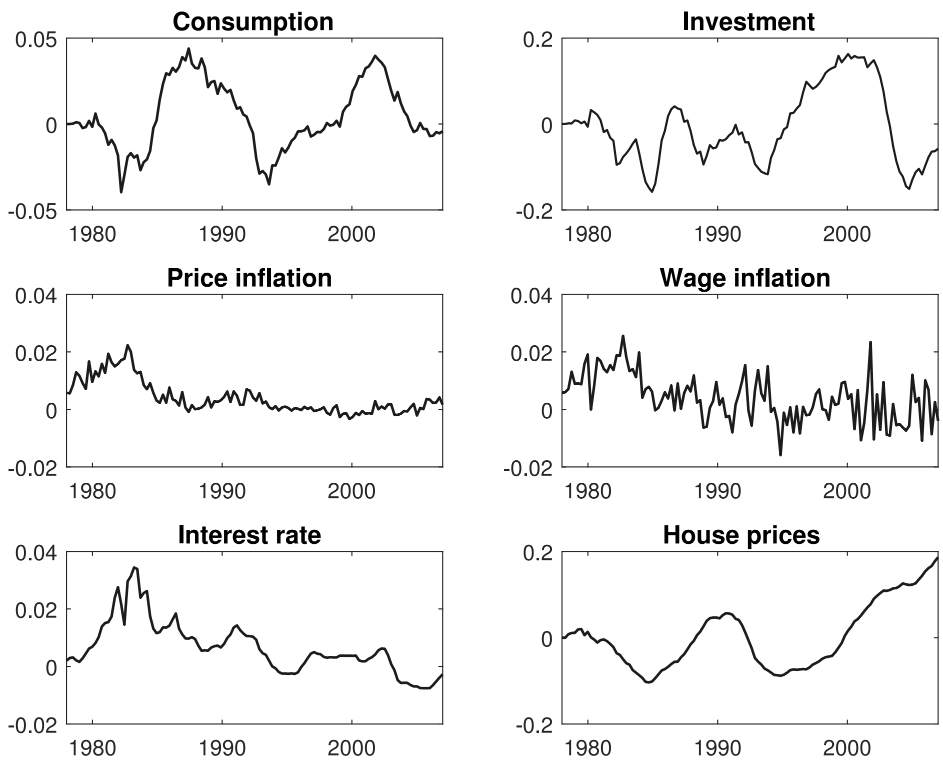
iii) **Price inflation**. Quarterly change in GDP implicit price deflator, minus 0.5 percent.
Model variable: $\tilde{\pi_t} = \log(\pi_t/\pi)$.

iv) **Wage inflation**. Real compensation per hour in the nonfarm sector, log transformed, detrended with HP filter, first differenced, and expressed in nominal terms adding back price inflation.
Model variable: $\tilde{\omega_t} = \log((\sigma\omega_t + (1-\sigma)\omega'_t)/\pi)$.

v) **House Prices**. Corelogic House Price Index divided by the GDP implicit price deflator, log transformed and detrended with one-sided HP filter.
Model variable: $\tilde{Q}_t = \log(q_t/q)$.

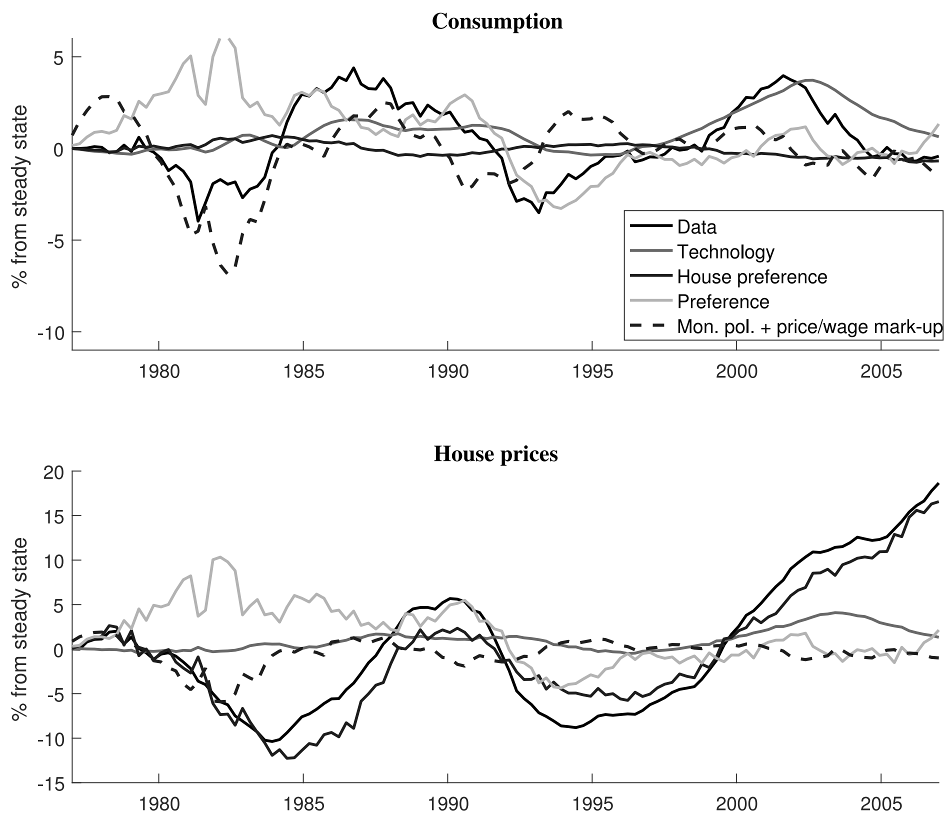
vi) **Investment**. Real private nonresidential fixed investment, log transformed and detrended with HP filter.
Model variable: $\tilde{i}_t = \log(i_t/i)$.

Figure B1: Time series of observables variables



Note: The figure displays the series of raw data, after applying all the transformations described above.

Figure B2: Historical variance decomposition of consumption and house prices



Note: It can be seen that the housing preference shock almost entirely explains the path of house prices whereas little is due to the role of the monetary policy shock. This implies that the huge increase in house prices, which likely fuelled the credit boom, was originated in the housing market through a sudden increase in the demand for housing. The impact of housing shock onto consumption instead appears to be quite subdued, in line with findings in Iacoviello (2005) and Iacoviello and Neri (2010).