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R&D, GROWTH, AND MACROPRUDENTIAL POLICY IN AN ECONOMY UNDERGOING BOOM-BUST CYCLES[*]

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Abstract

Recent evidence suggests that credit booms and asset price bubbles may undermine economic growth even as they occur, regardless of whether a crisis follows, by crowding out investment in more productive, R&D-intensive industries. This paper incorporates Schumpeterian endogenous growth into a DSGE model with credit-constrained entrepreneurs to show how shocks affecting firms' access to credit can generate boom-bust cycles featuring large fluctuations in land prices, consumption, and investment. During the expansion, rising land prices tend to crowd out capital and (especially) R&D investment: in the long run, this results in lower productivity levels, which in turn implies lower levels of aggregate output and consumption. Moreover, higher initial loan-to-value ratios tend to be associated with larger macroeconomic fluctuations. A counter-cyclical LTV ratio targeting credit growth has relevant stabilization effects but brings about small gains in terms of long-run consumption levels, and thus of welfare.

Keywords: Schumpeterian Growth, Financial frictions, Land prices, Macroprudential policy

JEL Classification: E22, E32, E44, O30, O40.

1 Introduction

The recent financial crisis has prompted a renewed interest in the causes and mechanisms of large boom-bust cycles featuring excessive investment and asset accumulation in some sectors of the economy. Specifically, since the crisis was triggered by a burst in the US housing bubble, a great deal of effort has been devoted to understanding the links between the housing market and the macroeconomy. It is well known that positive shocks which impact on house prices can easily propagate from the housing market to the rest of the economy and have an important influence on macroeconomic fluctuations.

Recent research, for instance by Brunnermeier and Schnabel (2015) and Jordà et al. (2015), points to credit-financed housing price bubbles as posing a particularly serious threat to both the financial system and the real economy. They find that although housing bubbles can be in general more disruptive than equity market ones, the financing of the bubble is crucial; upon collapse, the ensuing crises are most severe when the bubbles were accompanied by a lending boom and high leverage.

The housing boom of the mid-2000s in the US has been associated with heavily and rapidly increasing leveraged borrowing as well as with a persistent rise above trend of housing and consumption demand in the absence of significant productivity gains followed by a sharp fall below trend levels once the bubble burst. These features of the data can be described using DSGE models with collateral constraints à la Kiyotaki and Moore (1997) that explain credit booms and busts as the outcome of financial accelerators and balance sheet effects.

Along these lines, Iacoviello (2005), Iacoviello and Neri (2010), Justiniano et al. (2015) incorporate collateral constraints into a real business cycle model with heterogeneous agents, assuming that a subset of households use land or houses as collateral to finance consumption expenditures. The assumption of credit-constrained households allows us to explain some features of the data at business cycle frequencies, such as the procyclicality and the volatility of housing prices and investment, the positive co-movement between house prices and consumption expenditure, or the run-up of housing prices during the years leading up to the Great Recession. Some authors assume that firms, instead of households, are credit constrained, in order to account as well for the positive co-movement between land prices and business investment, which was especially observed during the recent crisis but is hardly accounted for by models with constrained households, as noted by Iacoviello and Neri (2010) and Liu et al. (2013). Among these, Liu et al. (2013) show that the use of land as a collateral asset to finance firms' investment provides a possible explanation for the observed large fluctuations in land prices and for the co-movements with other macroeconomic variables over the business cycles. Indeed, when firms are financially constrained by land values, a positive shock to land demand originating in the household sector raises the entrepreneur's net worth and thus expands his borrowing capacity. By triggering a competing demand for land between the household and business sectors, the credit expansion sets off a financial spiral that propagates the effects of the shock to the whole economy. Using US data, they propose that such shocks are the main driver of investment and output fluctuations. This finding is in line with Justiniano et al. (2015), who suggest that fluctuations in house prices, driven by factors other than credit availability, provide a closer account (as compared to exogenous increases in the loan-to-value ratio) of the credit cycle and its aggregate macroeconomic consequences.

By assuming credit-constrained entrepreneurs, Pintus and Wen (2013) show that the interaction between habit persistence and credit market frictions can also generate hump-shaped dynamics and boom-bust cycles as a consequence of one-time productivity shocks.

This class of models, which embeds housing and financial frictions in a dynamic stochastic general equilibrium setting, has been adopted by a growing strand of literature that investigates the effects of macroprudential policies, often in the form of counter-cyclical loan-to-value (LTV) ratios or capital requirements. Among these[1], Rubio and Carrasco-Gallego (2014) study the impact of a macroprudential rule for the LTV ratio on the business cycle, financial stability, and welfare, as well as its interaction with monetary policy. A similar analysis of the optimal design of monetary and macroprudential policies is conducted within a two-country setting by Mendicino and Punzi (2014) and Quint and Rabanal (2014) –in an estimated DSGE model of the Euro Area– and by Lambertini et al. (2013) –in a calibrated closed-economy– and Mendicino and Punzi (2014) in models where credit cycles are driven by news shocks rather than by financial shocks. The literature indicates that in the presence of financial shocks, a counter-cyclical macroprudential rule which targets financial variables, such as house price dynamics or credit growth, may yield significant gains in terms of macroeconomic stabilization and welfare, although a trade-off between the welfare of Savers and Borrowers can arise.

This paper aims to assess the effectiveness of dynamic LTV requirements in mitigating macroeconomic fluctuations driven by boom-bust cycles in land prices and their desirability from a welfare point of view. Diverging from existing literature, the analysis is conducted in the context of an endogenous growth model. The rationale for the adoption of a growth framework, as pointed out by Benigno (2013), is that it allows for a full appreciation of the effects of prudential policies by taking into account the permanent level effects caused by crisis events. If, as Comin and Gertler (2006) suggest, high-frequency non-technological disturbances can influence the pace of R&D activities, the effects of such shocks can then extend far beyond the business cycle frequencies and impose larger welfare costs because of their effect on growth. In order to capture these effects, I rely on the real business cycle model with heterogeneous agents and credit limits of Liu et al. (2013) and extend it to incorporate Schumpeterian endogenous growth and knowledge spillovers à la Aghion and Howitt (1998), as modeled in a DSGE setting by Nuño (2011). This framework, where growth is the result[2] of R&D activities undertaken by maximizing entrepreneurs, is especially suitable for studying the response of R&D to different shocks and, more generally, the links between changes in the value of firms' assets and the allocation of investment resources.

Schumpeterian models often result in the fraction of savings allocated to R&D activities being counter-cyclical. If investment choices are dictated merely by an opportunity-cost effect, since the opportunity cost of R&D is lower in recessions, these would be expected to ultimately promote innovation. Countering this prediction, recent studies show that R&D expenditures may in fact be pro-cyclical, and that they drop in a recession. Among these, Barlevy (2007), who explains this as the result of dynamic externalities that encourage entrepreneurs to concentrate innovations in booms, even if this concen-

[1]A more extensive review of this literature can be found in Agénor and Flamini (2016), who also study the optimal mix of monetary and macroprudential policy rules in an estimated DSGE model of the euro area.

[2]As in Liu et al. (2013), I assume that the growth rate of the economy depends on productivity growth and (exogenous) investment-specific technological change. Unlike Liu et al. (2013), however, I assume that productivity growth, although still subject to exogenous shocks, depends on endogenously determined R&D investment decisions.

tration is not socially optimal. Aghion et al. (2010) argue that the procyclical behavior of productivity-enhancing investment may be due to firms being credit constrained. This feature of R&D expenditures can exacerbate the costs associated with recessions by making these more persistent and the return to balanced growth more costly.

Moreover, recent literature on the effects of credit booms and asset price bubbles highlights that such phenomena, in addition to the risk of precipitating the economy into a protracted recession, may undermine economic growth even as they occur, regardless of whether or not a crisis follows. In this regard, Cecchetti and Kharroubi (2015) find that an exogenous increase in financial sector growth can harm productivity growth by inducing resource misallocations; the credit expansion may disproportionately benefit investment projects with high collateral but low productivity while crowding out more productive sectors, especially highly R&D-intensive industries. This view is supported by Borio et al. (2016), who find evidence of labor reallocations towards sectors with lower productivity growth as a consequence of credit booms, and by Chirinko and Schaller (2011), who argue that stock market bubbles lead to capital misallocation and over-investment in firms with poor investment opportunities.

By incorporating endogenous R&D-led innovation into a DSGE framework with financial frictions, this paper attempts to explain these features of the investment dynamics during boom-bust cycles, allowing for a better evaluation of the welfare gains associated with stabilization policies. The modelling framework assumes an economy populated with two agents, namely, households (Borrowers) and entrepreneurs (Savers). Borrowing is subject to an LTV constraint, so that loans need to be collateralized against a fraction of the value of the assets (land) that the Borrower owns. Borrowed funds are allocated between consumption and investment, which in turn can be used to buy land, capital or to undertake R&D. I calibrate a version of the model that replicates some key dynamic and long-run features of the US economy over the last four decades, using it to assess the impact of several financial and real shocks to evaluate the stabilization and welfare effects of a macroprudential rule that automatically reduces the LTV ratio when the economy overheats. The financial shocks considered here are of two types: an exogenous increase in the LTV ratio, and a positive shock to households taste for housing services, which triggers a run-up in land prices. Following Justiniano et al. (2015), the former can be intended as a loosening of lending standards due to either deregulations or innovations in the financial market, while the latter is meant to capture other factors (frictions or some deeper shocks) unrelated to credit availability and not modeled here, leading to an increase in house valuations.

Both shocks drive up land prices, which results in increased borrowing capacity for the firms and facilitates a protracted expansion in consumption, investment, and production, followed by the opposite dynamics as the effects of the shock vanish. However, the initial increase in the capital accumulation rate is short-lived, while R&D spending starts declining right after the initial boom. Nonetheless, the competing demand for land keeps pushing up land prices, whose increase stimulates aggregate consumption, even after production has begun to slow down. With diminishing marginal returns to capital and land, however, rising debt levels will eventually erode entrepreneurs' demand for consumption and land, laying the ground for a turnaround in the land price dynamics. Falling land prices then reduce both agents' net worth, which depresses aggregate demand. As a result, production capacity and output decline at an increasing speed, precipitating the economy into a recession followed by a prolonged period of subdued economic performance. Over the long term, the net effect of the fluctuations of R&D activities during a boom-bust cycle induced by financial shocks is a reduced level of productivity, which in turn results in lower levels of aggregate output and consumption. Both effects, especially that on productivity, tend to be small.

The length of each cycle is about six years, which is consistent with the results reported in Mendoza and Terrones (2012) on the effects of credit booms. Only the shock to the LTV ratio, however, is associated in this model with a boom in firms' loans. This shock is also associated with much larger fluctuations in all the macroeconomic aggregates, suggesting that shocks which directly affect credit availability explain better than shocks to asset valuations the boom-bust cycles of the kind observed during the recent financial crisis. This result counters Liu et al. (2013) and Justiniano et al. (2015), who find shocks to housing demand to be a more important source of macroeconomic fluctuations, but it is in line with Jermann and Quadrini (2012), who stress the importance of financial shocks that affect firms ability to borrow as a driver of business cycle movements.

The simulations show that an exogenous productivity shock is also capable of generating similar movements, with a protracted hump-shaped expansionary phase followed by an excessive contraction, due to declining land prices that lead to insufficient aggregate savings during the downturn phase of the cycle. Indeed, a positive technology shock stimulates entrepreneurs' investment spending. The rise in production possibilities prompts households to increase consumption and housing expenditure, thus triggering competing demand for land and the financial multiplier effect. These results are consistent with the findings of Pintus and Wen (2013) and Jensen et al. (2015) on the role of credit constraints as a source of propagation and amplification of shocks to technology or credit conditions.

Overall, the two financial shocks combined emerge in this model as the major driver of fluctuations in the main economic aggregates. At the same time, TFP shocks also explain a large share of volatility in output growth as well as in land price and R&D investment, due to the amplification effect of collateral constraints. The model also incorporates investment-specific technology shocks which, consistently with recent DSGE literature, play a minor, but not irrelevant, role in driving output and investment fluctuations.

The model also shows that higher initial values of the LTV ratio tend to be associated with larger fluctuations and a shorter expansionary phase followed by a deeper recession when the economy is hit by financial or productivity shocks.

The second part of the paper is thus devoted to assessing the effects of an LTV requirement that responds counter-cyclically to changes in the growth rate of output or to financial variables such as land prices or credit. The impulse response functions show that a rule targeting output is effective in dampening the economy's response to both financial and productivity shocks, although a rule that targets credit growth should be preferred in response to a shock to lending standards: by directly tackling credit, such a rule hampers the amplification effect of the collateral constraint. The use of a counter-cyclical response of the LTV ratio to land prices can also mitigate the consequences of the "bubble" burst by relaxing the borrowing constraint during periods of recession, but overall it is less effective in stabilizing the economy. The welfare-maximizing rule prescribes strong reactions to credit growth, while alternative rules targeting output or land prices, even if effective in stabilizing the economy, are not welfare-improving. At any rate, welfare gains under the optimizing rules are small (between 0.07% and 0.2% in consumption-equivalent terms for each representative agent). In fact, as the analysis is performed in the context of a growth model, the level effects are particularly relevant for welfare evaluation: as noted above, once the boom and the bust phases of the cycle are both taken into consideration, over the long term the net effect on the levels of consumption and output is small, and so are the welfare gains.

Sensitivity analysis shows that the utility specification assumed strongly affects the ability of the model to describe boom-bust cycles as well as its welfare results. When constant relative risk aversion (CRRA) preferences are introduced, financial shocks result in less intense expansions followed by a smoother return to balanced growth, whereas TFP shocks fail to inject boom-bust cycles. At the same time, substantial welfare gains stem now from the introduction of a macroprudential policy rule.

The rest of the paper is organized as follows. The next section describes the model. Section 3 discusses the calibration of the model and the impulse responses to several shocks. Section 4 investigates the effects of an LTV rule: impulse responses associated with simple rules are shown, and then the quantitative implications of optimized rules are discussed. Section 5 concludes the paper.

2 The model

The model builds on Nuño (2011) and Liu et al. (2013) by integrating endogenous growth into a real business-cycle framework with credit-constrained firms. Endogenous growth is based on vertical innovations à la Aghion and Howitt (1998). Schumpeterian theory allows the introduction of an endogenous driving process for productivity growth, based on the amount of R&D activities undertaken by entrepreneurs who maximize the expected profit stream from innovation. In such a framework, permanent effects on productivity levels may result from disturbances that affect investment allocation, especially the dynamics of R&D spending, as is the case with shocks that in the presence of financial frictions generate boom-bust cycles.

Therefore, this appears to be a suitable framework for describing the links between R&D, innovations and business cycles, and their effects over the medium to long term. These features, however, are also common to other approaches, such as expanding variety models à la Romer (1990). For the purpose of this work, the two approaches lead to similar results.

I depart from Nuño (2011) by assuming heterogeneous agents as in Liu et al. (2013): Savers (households) who serve the role of financial intermediaries and derive utility from consumption, leisure and land services (housing); and credit-constrained Borrowers (entrepreneurs). The latter derive utility from consumption goods only and are assumed to be more impatient than the representative household. Entrepreneurs can borrow to finance their consumption and investment spending, but, because of costly contract enforcement, lenders have incentives to lend only if the loan is secured by entrepreneurs' land holdings. Once they obtain funding, entrepreneurs can choose whether to invest in capital for the production of intermediate goods or in R&D activities, or to increase their land holdings.

A homogeneous final good is produced by competitive firms using labor, land, and a continuum of intermediate goods, which vary in productivity. Each of them is produced by a monopolistic competitive firm using an amount of capital which is proportional to the complexity of the economy. Following Aghion and Howitt (1998) and Nuño (2011), I am assuming lab-equipment R&D: research uses a great deal of physical capital in the form of laboratories and machinery, and more advanced products require increasingly capital-intensive techniques. By investing in R&D activities, entrepreneurs increase the probability that they will make a discovery. If this happens, an improved version of the existing intermediate input is produced, and the successful entrepreneur will operate as a monopolist in her sector until she is replaced by the next innovator. Each innovation raises productivity in its sector to the technology frontier and contributes to its expansion as a result of knowledge spillovers.

2.1 Households

The model assumes an economy populated by two types of agents: (patient) households, which derive utility from consumption goods (C_t^h), housing services (L_t^h) and leisure, and (impatient) entrepreneurs, whose utility depends only on consumption. Households neither produce nor accumulate capital goods; they provide labor to final producers and loans to entrepreneurs, thus playing the role of financial intermediaries in the economy.

The representative household maximizes the following utility function à la Jaimovich and Rebelo (2009):

$$\max \sum_{t=0}^{\infty} (\beta^h)^t [\log(C_t^h - \rho^h P_t N_t^{\zeta}) + \chi_t \log L_t^h], \tag{1}$$

where N_t denotes labor hours, $\rho^h > 0$ measures the disutility of labor, and $\beta^h \in (0,1)$ is the household's discount factor. The variable P_t is an index equal to the geometric average of current and past consumption, that is:

$$P_t = (C_t^h)^{\nu} P_{t-1}^{1-\nu}. \tag{2}$$

Here, the parameter $\nu \in (0,1)$ governs the magnitude of the wealth elasticity of labor supply. If $\nu = 0$, the parameter $\zeta > 0$ determines the Frisch elasticity of labor supply. In this special case, the utility function reduces to the Greenwood, Hercowitz, and Huffman (1988) preference specification, where anticipated changes in income do not affect current labor supply. As is well known, GHH preferences are not consistent with a balanced growth path; thus, I will assume a positive, but close to zero, value for ν, so as to minimize the strength of the wealth effect on labor supply while preserving compatibility with long-run balanced growth. Finally, the term χ, which measures the household's taste for housing services and will be referred to as a housing or land demand shock, follows the stochastic process

$$\log \chi_t = (1 - \rho_{\chi}) \log \bar{\chi} + \rho_{\chi} \log \chi_{t-1} + z_{\chi,t}, \tag{3}$$

where $\bar{\chi}$ is a constant, $\rho_{\chi} \in (0,1)$ is the persistence parameter, and $z_{\chi,t}$ is $i.i.d.N(0, \sigma_{\chi}^2)$.

The representative household uses labor income together with interest income from payment on previous loans to finance current consumption and land investment. She is endowed with L_{t-1}^h units of initial land. Her budget constraint is given by:

$$C_t^h + Q_t^l (L_t^h - L_{t-1}^h) + B_t / R_t \leq W_t N_t + B_{t-1}, \tag{4}$$

where Q_t^l is the relative price of land, R_t is the gross real loan rate, W_t is the wage rate, and B_t represents a loanable bond purchased in period t that pays off one unit of consumption good after one period. The first-order conditions for the household's optimizing problem with respect to consumption, working hours, land investment, the consumption index P_t and lending are given, respectively, by

$$\Lambda_t^h = 1/(C_t^h - \rho^h P_t N_t^\zeta) - \Xi_t \nu \frac{P_t}{C_t^h} \tag{5a}$$

$$W_t \Lambda_t = \frac{\zeta \rho^h P_t N_t^{\zeta-1}}{C_t^h - \rho^h P_t N_t^\zeta} \tag{5b}$$

$$\Lambda_t^h Q_t^l = \frac{\chi_t}{L_t^h} + E\beta^h \Lambda_{t+1}^h Q_{t+1}^l \tag{5c}$$

$$\Xi_t = \frac{\rho^h N_t^\zeta}{C_t^h - \rho^h P_t N_t^\zeta} + \beta^h E \Xi_{t+1}(1-\nu)\frac{P_{t+1}}{P_t} \tag{5d}$$

$$1/R_t = E\beta^h \frac{\Lambda_{t+1}^h}{\Lambda_t^h}, \tag{5e}$$

where Λ_t^h is the Lagrangian multiplier associated with the budget constraint and Ξ_t is the multiplier associated with the constraint in (2).

2.2 Entrepreneurs

The representative entrepreneur maximizes the utility from a stream of consumption goods, according to the following function:

$$\max E \textstyle\sum_{t=0}^{\infty} (\beta^e)^t \log(C_t^e - \rho^e C_{t-1}^e),$$

where C_t^e denotes consumption, β^e is the subjective discount factor of entrepreneurs, and ρ_e measures the degree of habit persistence. The entrepreneur is assumed to be more impatient than households; hence, the time discount factor $\beta^e \in (0,1)$ satisfies $\beta^h > \beta^e$. She is initially endowed with K_{t-1} units of capital stock and L_{t-1}^e units of land. Capital accumulation is subject to a quadratic adjustment cost and follows the law of motion:

$$K_t = (1-\delta)K_{t-1} - \left[1 - \frac{O}{2}\left(\frac{I_t}{I_{t-1}} - \bar{g_I}\right)^2\right] I_t, \tag{6}$$

where I_t is investment in physical capital, O is the adjustment cost parameter, and $\bar{g_I}$ denotes the steady-state growth rate of investment. The entrepreneur purchases consumption goods, invests in land (L_t^e) and capital, which are both rented out to final and intermediate good producers respectively, and in R&D activities, and collects the profits (D_t) from a mutual fund that takes R&D investment decisions and manages the intermediate firms. Thus, the flow of funds constraint of the entrepreneur can be stated as:

$$C_t^e + Q_t^l(L_t^e - L_{t-1}^e) + \frac{I_t}{Q_t^k} \leq S_t L_t^e + \mu_t K_{t-1} + D_t - B_{t-1} + B_t/R_t, \tag{7}$$

where S and μ are respectively the rental rates of land and capital, B_{t-1} is the amount of matured debt and B_t/R_t is the value of new debt. The relative price of investment $(1/Q_t^k)$ decreases over time as Q_t^k increases. Indeed, following Greenwood et al. (1997)

and Liu et al. (2013), I interpret Q_t^k as the investment-specific technological change (IST) and assume that it follows the stochastic process

$$Q_t^k = Q_{t-1}^k g_q; \qquad \log g_q = (1-\rho_{qk}) \log \bar{g_q} + \rho_{qk} \log g_{q,t-1} + z_{Q,t}, \tag{8}$$

where $\bar{g_q}$ is the steady-state growth rate of technology embodied in physical capital, $\rho_{qk} \in (0,1)$ is the persistence parameter, and $z_{Q,t}$ $i.i.d.N(0,\sigma_Q^2)$.

Moreover, the entrepreneur faces the following borrowing constraint, reflecting that, due to limited contract enforceability, the lender has incentives to lend only if the loan is secured by the value of a collateral:

$$B_t \leq \theta_t E Q_{t+1}^l L_t^e, \tag{9}$$

where θ_t is the LTV ratio and reflects the tightness of credit markets related to financial innovation or regulations. Following Kiyotaki and Moore (1997) and Pintus and Wen (2013), only land holdings can be used as collateral, while reproducible capital is assumed to be firm-specific, so that it does not have collateral value. The borrowing constraint imposes that the amount which the entrepreneur can borrow cannot exceed a fraction of the collateral value of assets owned by the borrower in the next period. A large strand of literature, starting with Kiyotaki and Moore (1997) and including more recently Pintus and Wen (2013), Liu et al. (2013), Jensen et al. (2015), and Hirano and Yanagawa (2017) introduces the LTV ratio either as a fixed parameter or as an exogenous collateral shock following a highly persistent stochastic process. As against this approach, a fast-growing literature has been investigating the implications of adopting counter-cyclical LTV ratio requirements as macroprudential tools. Indeed, caps on the LTV ratio have already been used in several countries to curb rapid credit growth and mitigate house price cycles, especially when the use of policy interest rates is constrained. Thus, I will assume a Taylor-type rule for the LTV ratio reacting inversely to the growth rates of GDP and of a financial variable such as land prices or credit, as in Rubio and Carrasco-Gallego (2014). However, in order to maintain comparability with the former strand of literature, and consistent with the results obtained by Jermann and Quadrini (2012) and Liu et al. (2013), who find that financial shocks affecting firms' ability to borrow explain an important fraction of fluctuations in investment, output, and labor hours [3], I hereby allow for the occurrence of temporary shocks to credit availability. This approach is similar to that found in Mendicino and Punzi (2014).

The loan-to-value ratio, thus, evolves over time as follows:

$$\log \theta_t = (1-\rho_\theta) \log \bar{\theta} + \rho_\theta \log \theta_{t-1} - \rho_y \log \left(\frac{Y_t / Y_{t-1}}{\bar{g}} \right) - \rho_q \log \left(\frac{\iota_t / \iota_{t-1}}{\bar{g}} \right) + z_{\theta,t}, \tag{10}$$

where $\bar{\theta}$ is the steady-state value of the LTV ratio, $\bar{g}$ is the equilibrium growth rate of the economy, $\rho_y, \rho_q \geq 0$ measure the response to the growth rate of, respectively, output and a variable (ι) measuring financial conditions, the parameter $\rho_\theta \in (0,1)$ measures the degree of persistence, and $z_{\theta,t}$ is i.i.d. $N(0, \sigma_\theta^2)$.

[3] Liu et al. (2013) estimate that credit shocks alone account for about 6-12% of the volatility in output, 12-16% in investment, and 10-14% in hours, depending on the horizon considered.

Maximizing (2.2) subject to (7) and (9) with respect to consumption, capital investment, land investment, and borrowing leads, respectively, to the following first-order conditions:

$$\Lambda_t^e = 1/(C_t^e - \rho^e C_{t-1}^e), \tag{11a}$$
$$\Phi_t^k = \beta^e E\left[\mu_{t+1}\Lambda_{t+1}^e + (1-\delta)\Phi_{t+1}^k\right], \tag{11b}$$
$$\Lambda_t^e Q_t^l = \Phi_t^b \theta E Q_{t+1}^l + \beta^e E \Lambda_{t+1}^e (Q_{t+1}^l + S_{t+1}), \tag{11c}$$
$$\Lambda_t^e / R_t = E\beta^e \Lambda_{t+1}^e + \Phi_t^b, \tag{11d}$$
$$\frac{\Lambda_t^e}{Q_t^k} = \Phi_t^k \left[1 - \frac{O}{2}\left(\frac{I_t}{I_{t-1}} - \bar{g_I}\right)^2 - O\left(\frac{I_t}{I_{t-1}} - \bar{g_I}\right)\frac{I_t}{I_{t-1}}\right] + \beta^e E\Phi_{t+1}^k O\left(\frac{I_{t+1}}{I_t} - \bar{g_I}\right)\left(\frac{I_{t+1}}{I_t}\right)^2, \tag{11e}$$

where Λ_t^e is the Lagrangian multiplier associated with the flow of funds constraint, Φ_t^b is the multiplier of the borrowing constraint, and Φ_t^k is the multiplier of the capital accumulation equation. Equation (11c) shows that the relative price of land depends on the sum of its discounted marginal product and resale value, plus the value of land as a collateral asset for borrowing. By combining equations (11d) and (5e), it is also clear that the borrowing constraint is binding, which means $\Phi_t^b > 0$, if and only if the interest rate is lower than the entrepreneurs intertemporal marginal rate of substitution, which is implied in a steady state by our assumption that $\beta^h > \beta^e$.

2.3 Final goods

The description of the productive sector in this and the next sub-sections closely follows Nuño (2011). Final goods (Y_t) are produced under perfect competition using labor, land (intended, for calibration purposes, as nonresidential structures) and a continuum of intermediate products. Final-goods producers maximize their profits:

$$\max_{L_{t-1}^e, m_{j,t}, N_t} Y_t - W_t N_t - S_t L_{t-1}^e - \int p_{j,t} m_{j,t} dj \tag{12}$$

subject to:

$$Y_t = Z_t N_t^{1-\alpha-\gamma} (L_{t-1}^e)^\gamma \left(\int_0^1 A_{j,t} m_{j,t}^\alpha dj\right) \tag{13}$$

where L_{t-1}^e is the amount on land used in production, for which the firms pay a price S_t, $m_{j,t}$ is the amount of intermediate product $j \in [0,1]$, N_t is labor supply, and $A_{j,t}$ is a productivity parameter associated with the latest version of the intermediate good j. I assume that the total factor productivity (TFP) depends on an endogenous component (the productivity of intermediate goods) and an exogenous TFP shock (Z_t) that follows the AR(1) process

$$\log Z_t = (1-\rho_Z)\log \bar{Z} + \rho_Z \log Z_{t-1} + z_{Z,t}, \tag{14}$$

with $z_{Z,t}$ i.i.d. $N(0, \sigma_Z^2)$.

The first-order conditions are given by:

$$p_{j,t} = A_{j,t} Z_t N_t^{1-\alpha-\gamma} (L_{t-1}^e)^\gamma m_{j,t}^{\alpha-1} \tag{15a}$$

$$W_t = (1-\alpha-\gamma) Y_t / N_t \tag{15b}$$

$$S_t = \gamma Y_t / L_{t-1}^e \tag{15c}$$

The price of final output is normalized to 1. Final output can be used interchangeably as a consumption good, input to R&D activities or investment in fixed capital.

2.4 Incumbents

In each sector there is an incumbent monopolist who maximizes profits from selling an intermediate good:

$$\max_{m_{j,t}} \left(p_{j,t} m_{j,t} - \mu_t K_{j,t-1} \right), \tag{16}$$

where $K_{j,t-1}$ is the capital in sector j at time t, installed in period $t-1$ and μ_t is the rental cost of capital. Each intermediate good is produced using capital, according to the production function:

$$m_{j,t} = K_{j,t-1} / A_{j,t}. \tag{17}$$

The amount of capital necessary for the production of each intermediate good is proportional to its productivity, reflecting the fact that more advanced products require increasingly capital-intensive techniques. Maximizing (16) subject to (15a) and (17) leads to the following equilibrium level for the cost of capital:

$$\mu_t = \alpha^2 Y_t / K_{t-1}. \tag{18}$$

Since the sector productivity enters proportionally both the marginal revenues and the marginal cost in (16), all incumbents will produce the same amount of the intermediate product:

$$m_t = \left(\frac{\alpha^2 N_t^{1-\alpha-\gamma} (L_{t-1}^e)^\gamma}{\mu_t} \right)^{\dfrac{1}{1-\alpha}}.$$

Then, the aggregate capital of the economy is given by

$$K_{t-1} = \textstyle\int_0^1 K_{j,t-1} d_j = m_t A_t, \text{ where } A_t = \textstyle\int_0^1 A_{j,t} d_j$$

is the average productivity across all sectors. As a result, the aggregate production function of the economy can be rewritten as:

$$Y_t = Z_t A_t^{1-\alpha} N_t^{1-\alpha-\gamma} (L_{t-1}^e)^\gamma K_{t-1}^\alpha. \tag{19}$$

Additionally, by substituting in (16), we can derive the following expressions for the flow of profits of each incumbent and aggregate profits:

$$\Pi_t(A_{j,t}) = \frac{\alpha(1-\alpha) Y_t}{A_t} A_{j,t}; \tag{20a}$$

$$\Pi_t = \alpha(1-\alpha) Y_t. \tag{20b}$$

2.5 Productivity

In each period, there is one researcher per sector devoting resources to R&D activities in an attempt to increase the probability that she will make a discovery. If a discovery occurs, it allows the innovator to produce an enhanced version of the existing intermediate good in her sector, thus displacing the incumbent and becoming the new monopolist, until the next innovation in the same sector is available. That is, it is assumed that the researcher who has made a discovery in period t enters into Bertrand competition with the previous incumbent in her sector. Since the new entrant is offering a superior product, the incumbent will leave the market rather than start a fruitless price war. Hence, the former researcher is left to operate as the new incumbent monopolist in period $t + 1$. Each period, the probability $(n_{j,t})$ of a discovery in a given sector depends on the amount of resources spent on R&D activities (X_t) by the researcher according to the following function:

$$n_{j,t} = \left(\frac{X_{j,t} Q_t^k}{\psi K_t} \right)^{1/(1+\eta)}, \tag{21}$$

where $\psi > 0$ is a measure of the productivity of resources devoted to R&D, while $\eta \geq 0$ determines the extent of decreasing returns to scale in innovation. The amount of resources is adjusted by the existing capital stock in efficiency units, as a proxy for the degree of complexity of the economy: keeping the probability of new discoveries constant over time requires R&D investment to grow in the same proportion as capital accumulation, net of IST progress.

At any date, the state-of-the-art technology is represented by the most advanced productivity level across all sectors. The technology frontier (A_t^*) will be available to every researcher who makes a discovery in period t once she becomes the new incumbent. As a consequence, the productivity in sector j evolves according to:

$$A_{j,t+1} = \left\{ \begin{array}{ll} A_t^* & \text{with probability } n_{j,t} \\ A_{j,t} & \text{with probability } 1 - n_{j,t}. \end{array} \right\} \tag{22}$$

The technology frontier grows gradually, as innovation embodied in new intermediate goods spills over to the whole economy and becomes available to any innovator. Thus, each innovation endogenously pushes the technology frontier in proportion to the aggregate flow of innovations by a factor $(1 + \epsilon)$, with ϵ being the knowledge spillover coefficient. That is:

$$g_t^a = \frac{A_t^*}{A_{t-1}^*} = \int \left[n_{j,t-1}(1+\epsilon) + (1 - n_{j,t-1}) \right] dj = 1 + \epsilon n_{t-1}. \tag{23}$$

R&D investment decisions are made by researchers in order to maximize the discounted value of becoming the incumbent in the next period $E_t \beta^e \Lambda_{t+1}/\Lambda_t [V_{j,t+1}(A_t^*)]$ weighted by the probability of being successful in innovating:

$$\max_{X_t} n_{j,t} \beta^e E_t \frac{\Lambda_{t+1}^e}{\Lambda_t^e} V_{j,t+1}(A_t^*) - X_{j,t}, \tag{24}$$

given (21). The value of being the incumbent in period t in a sector with productivity $\bar{A}, V_{j,t}(\bar{A})$ is the discounted flow of profits that the incumbent may obtain by taking into account the probability of being displaced by a new innovator in the following periods:

$$V_{j,t} = \Pi_{j,t} + (1 - n_{j,t})\beta^e E_t \frac{\Lambda^e_{t+1}}{\Lambda^e_t}[V_{j,t+1}]. \tag{25}$$

Since the value of being the incumbent in the next period depends on the level of the technology frontier, it is the same for all sectors. Therefore, all researchers face the same problem; the input invested in R&D is the same across all sectors ($X_{j,t} = X_t$) and so is the probability of an innovation occurring ($n_{j,t} = n_t$).

Maximizing (24) leads to the following first-order condition requiring equivalence between the marginal cost of allocating an extra unit of good to research and the discounted marginal expected benefit:

$$X_t = \frac{n_t}{1+\eta}\beta^e E_t \frac{\Lambda^e_{t+1}}{\Lambda^e_t} V_{t+1}(A^*_t). \tag{26}$$

As in Nuño (2011), I assume that R&D is financed by a mutual fund in exchange for the ownership of the new incumbent firms from which it collects the profits $D_t = \int_0^1 (\Pi_t A_{j,t} - X_{j,t})dj = \Pi_t - X_t$.

2.6 Equilibrium

A competitive equilibrium can be defined as a set of prices and allocations such that taking prices as given, the allocations solve the maximization problems of households, entrepreneurs, researchers, producers of final and intermediate goods, the usual transversality conditions hold, and all markets clear. The final-goods market clearing condition requires:

$$Y_t = C_t + \frac{I_t}{Q^k_t} + X_t, \tag{27}$$

where $C_t = C^e_t + C^h_t$ is aggregate consumption. Land-market clearing implies that

$$L^e_t + L^h_t = \bar{L}, \tag{28}$$

as land is in fixed supply. In equilibrium, the average productivity of the economy depends linearly on the number of sectors that experience an innovation and the distance to the technology frontier ($A^*_t - A_{t-1}$):

$$A_t = \int_0^1 [n_{j,t-1}A^*_{t-1} + (1 - n_{j,t-1})A_{j,t-1}]dj = n_{t-1}(A^*_{t-1} - A_{t-1}) + A_{t-1}. \tag{29}$$

The model exhibits a balanced growth path (BGP) along which all variables grow at a constant rate, except $g_t, g^a_t, N_t, L^e_t, L^h_t$, and n_t, which are constant. In order to study the fluctuations around the BGP, the variables growing over time are detrended, and lowercase letters will be used to denote the transformed, stationary version of the corresponding variables.

3 Numerical analysis

This section compares the dynamic responses of the model to the exogenous shocks described in the previous section. Specifically, after calibrating the model, I will describe the responses of some key variables following a sudden unexpected shock to the exogenous component of TFP (Z), the investment-specific technology (Q_k), and the two variables that determine financial conditions (the credit limit, θ, and households' preferences for land, χ), assuming that the borrowing constraint always binds near the steady state. In the next section, I will show how the introduction of a macroprudential policy rule targeting the LTV ratio modifies the model's response to shocks and its business cycle properties.

3.1 Calibration

The model is calibrated to replicate some key features of the US economy, using quarterly data from 1977 to 2014[4]. Unless otherwise is specified, I use data from NIPA tables of the Bureau of Economic Analysis (BEA).

Steady-state parameters The value of land holdings is calibrated using the average value of residential structures (for the housing services in the household's utility function) and non-residential non-farm structures (in the case of land used in production), which are equivalent to 1.44% and 0.86% of GDP respectively at annual frequency. This implies that in equilibrium households hold 63% of land. The average quarterly growth of GDP at annual rate per working-age person is 1.92%; assuming a real interest rate $log(R)$ of 3.9% per annum implies a value for the quarterly discount factor of 0.995 for the (patient) household. For the discount factor of the (impatient) entrepreneur, I pick a slightly lower value of 0.991. The preference for land parameter χ is set equal to 0.052 in steady state in order to match the value of structures used in production and the land's share (γ) of output, that I set to 2.1%, in line with the estimate by Liu et al. (2013). As to the LTV ratio, I use $\theta = 0.7$ as in Jensen et al. (2015): this value is close to those found by Liu et al. (2013) and Mendicino and Punzi (2014), and it is within the range of values typically used in the literature. In order to gain more insight into the effects of different LTV ratios on the macroeconomy, I will show the impulse responses under two alternative values of this parameter: a "high" LTV regime, where $\theta = 0.85$, and a "low" regime with $\theta = 0.55$. I assume a value of 0.35 for the capital income share, while the capital depreciation rate is set to 0.036, close to the values used by Jensen et al. (2015) –0.035– and Liu et al. (2013) –0.037–. This implies an investment share of GDP equal to 10.25% in equilibrium (the average over the considered period is 10.55%) and a capital-output[5] ratio of roughly 0.57, as observed in the data, at annual frequency. As to the investment adjustment cost parameter, O, the empirical estimates are varied; I choose a value of 0.37, close to the estimate by Liu et al. (2013). The labor disutility parameter κ and the parameter governing intertemporal substitution of labor ζ are set so as to obtain a value for the steady-state market hours equal to 25% of time endowment as in Liu et al. (2013), whose constructed series of per capita hours are used here. Specifically, I am assuming $\kappa = 3.16$ and $\zeta = 1.2$, which is the value found by Schmitt-Grohe and Uribe (2008) and also used

[4] The choice of the data period is due to data availability. Specifically, the last complete year of data on the relative price of investment goods is 2014, while seasonally adjusted data on the working age population at quarterly frequency, used here to derive per capita quantities, are not available before 1977. In both cases, the source is FRED.

[5] As the model assumes a lab-equipment specification of the R&D process, and capital is only used for the production of intermediate goods, it is intended here as the sum of the net stocks of nonresidential equipment and software.

by Arezki et al. (2015), while Jaimovich and Rebelo (2009) picks a value of 1.4, and somewhat higher values can be found in other studies. For the parameter determining the wealth elasticity of labor ν I pick a value of 0.023, which lies within the range of values considered by Jaimovich and Rebelo (2009).

Table 1: Calibration of the model

Steady-state parameters			
α	Output elasticity of capital		0.35
γ	Output elasticity of land		0.021
β^e	Borrower's discounting factor		0.991
β^h	Lender's discounting factor		0.995
δ	Depreciation rate of capital		0.036
ϵ	Spillover coefficient		0.087
ζ	Intertemporal substitution of labor		1.2
η	-		7.17
θ	LTV ratio		0.7
ν	Wealth elasticity of labor parameter		0.023
ρ^e	Habit coefficient for borrowers		0.73
κ	Labor disutility parameter		3.16
χ	Preference parameter for land		0.052
$\log\psi$	-		25.46
O	investment adjustment cost parameter		0.37
Shock parameters			
σ_θ	0.029	ρ_θ	0.9
σ_χ	0.16	ρ_χ	0.9
σ_Z	0.0015	ρ_Z	0.9
σ_Q	0.0033	ρ_Q	0.66

Parameter values used in simulations; quarterly benchmark calibration.

I calibrate the steady-state growth rate of the relative price of investment to be -0.48% per quarter in the postwar period (based on data between 1947:Q1 and 2015:Q3). Given this value for $1/g_q$, I set the growth rate of the technology frontier g_a to 0.22% in order to replicate the value of annual GDP growth of 1.92%. In setting the parameters that characterize the technology spillover ϵ and the relationship between R&D investment and business turnover (ψ, η), I follow Nuño (2011). Assuming an annual average business turnover rate for US firms equal to 10%, I set the spillover coefficient ϵ to 0.087 to be consistent with the growth rate of the technology frontier as defined in (23). I calibrate the parameter η that determines the productivity of R&D investment to be 7.17 in order to match the average R&D spending share (2.11%), and $log(\psi)$ to 25.46 in order to match the business turnover rate $n = 10\%$. Finally, I set the level of habit constraint for the entrepreneur to 0.73. The calibration of the model is summarized in table 1.

Shock parameters I calibrate the persistence parameters $(\rho_\theta, \rho_\chi, \rho_Z, \rho_Q)$ and the volatilities $(\sigma_\theta, \sigma_\chi, \sigma_Z, \sigma_Q)$ of the four shocks considered to replicate some second-order moments of interest: the volatility of the growth rates of output, consumption, land price and the two categories of investment; the correlations between these variables and GDP growth, the autocorrelation of GDP growth, and labor growth volatility. Parameter values are presented in table 1, while the simulated moments are shown in table 2. Simulated moments are computed by employing Monte Carlo methods: the model is simulated 3000 times with the length of each sample being 200 periods. As a proxy for deriving the volatility of land price, I use the Freddie Mac House Price Index.

The model is able to replicate the observed volatilities in output, consumption, and investment as well as the autocorrelation of GDP growth, but it explains less than half the observed volatility of land price. Additionally, the model accounts for the procyclicality of R&D investment and land prices as well as for the correlation between these two variables, although these tend to be overestimated. The steady-state results and second-order moments are reported in table 2.

Table 2: Steady state and second-order moments

Annual average			Second order moments		
Variable	Data	Benchmark	Variable	Data	Model
g	1.92%	1.92%	σ_y	2.38	2.38
g_q	1.96%	1.97%	σ_x	4.77	4.76
x/y	2.11%	2.11%	σ_c	1.72	1.72
i/y	10.55%	10.25%	σ_i	10.53	10.55
k/y	57%	56.57%	σ_{Q_l}	5.68	2.52
n	10%	10%	σ_N	3.24	2.77
b/y		60.21%	$\rho_{y_t,y_{t-1}}$	0.51	0.51
N	25.01%	25%	$\rho_{y,x}$	0.32	0.59
L_e		37%	$\rho_{y,c}$	0.89	0.92
R		3.9%	$\rho_{y,i}$	0.83	0.86
			ρ_{y,Q_l}	0.33	0.39
			$\rho_{Q_l,x}$	0.14	0.32
			$\rho_{Q_l,i}$	0.24	0.03

This table reports the simulated moments of some key variables. On the left side are the steady-state values at annual rates. Second-order moments (on the right side) refer to quarterly growth at an annual rate. Moments are computed by simulating the benchmark model 3000 times at quarterly frequency for 200 periods.

3.2 Quantitative implications

The following paragraphs illustrate the impulse responses of the model to a one standard deviation increase in the shock variables described above. The results for our benchmark calibration are compared to those obtained using the two alternative values for the LTV ratio. At the end of the chapter, results obtained under two alternative version of the model, one without IST change and one with CRRA preferences, are briefly presented. Model simulations generate a series of growth rates that are used to convert all the stationary variables, defined by lowercase letters, to their non-stationary counterparts, by multiplying each variable by the appropriate cointegrating factor. Hence, the impulse response functions show log-deviations of each variable, expressed in levels, from its steady-state linear growth trend.

Financial shocks Figures 1 and 2 show the model response to a housing demand shock and a credit shock, respectively. The two shocks trigger similar responses in the main variables, generating large oscillations of output, investment, labor hours, and a highly persistent, hump-shaped behavior of aggregate consumption. In the presence of credit constraints, thus, financial shocks that affect land prices propagate to the rest of the economy, triggering a financial multiplier through the dynamic interactions between land prices and investment.

In the present setting, a land demand shock that raises the weight of housing in the utility function makes households willing to reduce lending to the entrepreneurs in order to increase their consumption of housing services. The entrepreneurs, who are selling part of their land, will use the revenues to increase consumption, as well as investment and labor demand. Indeed, despite being impatient, the entrepreneurs are willing to smooth consumption, due to the assumption of habit persistence, thus increasing the investment response to a land-demand shock and potentially leading to over-investment and an excessive expansion of production capacity.

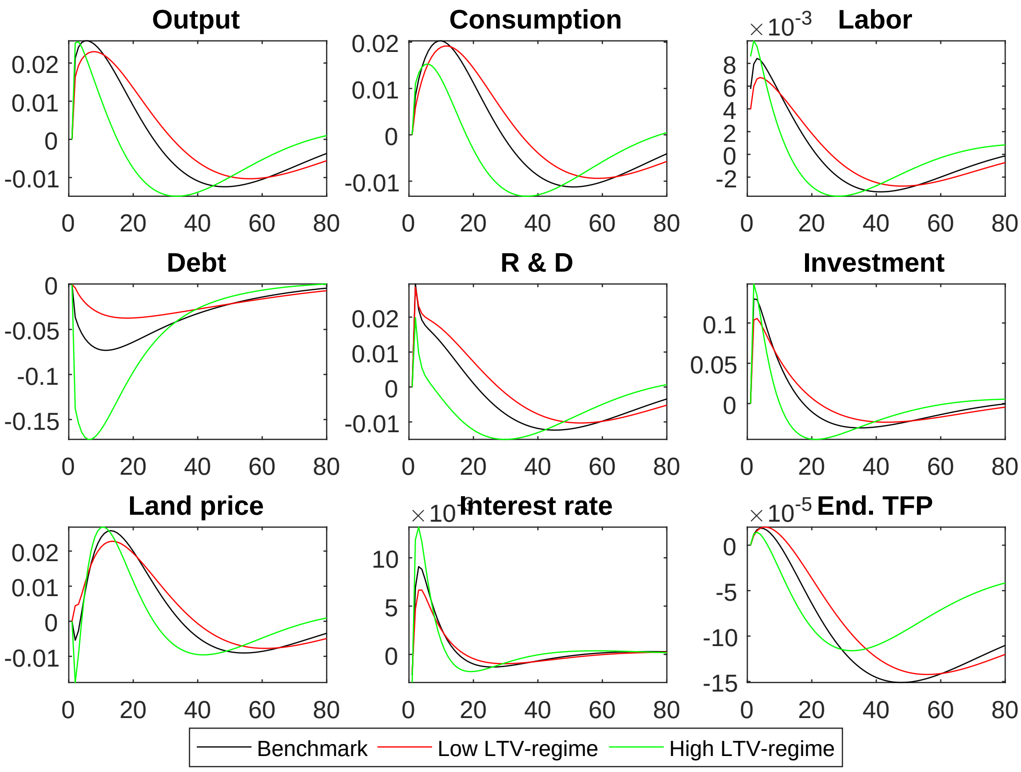

Figure 1: Impulse responses to a one standard deviation land preferences shock χ_t for different initial values of the LTV ratio: 0.7 (Benchmark), 0.55 (Low), 0.85 (High).

This is especially the case in R&D investment, whose initial increase is further reinforced by the effect of the adjustment cost on capital investment, so that R&D peaks in the first period and declines thereafter. As is the case with other shocks that lead to an output expansion, the potential market for successful entrepreneurs increases in size, and so do expected profits, thus driving R&D (and innovation) up. However, the prospects of higher profits, by inducing more investment in R&D activities, also raise the risk of being replaced by new entrants in the future, thus discouraging innovation. The net effect of this trade-off between higher profits and shorter monopoly rents is that, after the initial jump, R&D slowly declines in our benchmark calibration, anticipating the expected dynamics of the economy.

As production expands, the entrepreneurs will start buying back land, which has become more productive, thus triggering a competing demand with the household sector that drives land prices up. The increased valuation of the collateral asset raises the entrepreneur's net worth, thus allowing her to consume and invest more. However, as the marginal productivity of capital decreases, so do the expected profits associated with innovation. At the same time, land prices rise, causing the bulk of investment to shift toward buying more land. Rising land prices add to the initial expansion in output and employment in sustaining demand (for both consumption goods and housing) from households, continuing to fund an increase in aggregate consumption even as the economy begins slowing down, due to the substitution of more productive investment with land buying. Eventually, diminishing marginal returns on assets will weaken the entrepreneurs' financial position, thus resulting in reduced aggregate demand and a reversal of the land price trend. Falling land prices further undermine the agents' net worth, thus accelerating the contraction of the economy. This inversion of the multiplier accelerator mechanism turns the downturn into a recession followed by a slow recovery with aggregate demand lying below its long-run trend for a prolonged period.

The bottom-right panel reports the dynamics of the endogenous component of TFP, that is, the average technology level in the economy, A. Following a shock to land demand, TFP shows a bump, due to the boom in R&D investment and then declines, as the entrepreneurs allocate too many resources to the alternative types of investment[6]. Prolonged under-investment in R&D activities, which begins during the expansionary phase of the cycle and persists through the recession, implies that even in the long run the average technology level will be lower than it would have been without the shock, although the effect is very small because of the specification of n in eq (21).

As we can see from the figure, the sensitivity of land demand to shocks affecting access to credit is higher under looser credit conditions. Faced with heavier cuts to credit, the entrepreneurs sell more of their land, causing the land price to fall on impact. As they reinvest the revenues (mostly in physical capital, since expected profits from innovation are comparatively lower in this case) and the marginal productivity of land rises, the ensuing increase in land demand triggers an upward spiral of land prices that is faster than in our benchmark case. As a result, the boom will be shorter and the ensuing recession harsher, compared with the alternative LTV regimes considered.

Figure 2 shows that a similar dynamic is induced by a shock to the credit limit; however, since this impacts directly on the entrepreneur's borrowing capacity, the amplification effect is stronger in this case. The main difference lies in the credit response to the shock: the relaxation of the credit constraint leads entrepreneurs to increase their borrowing to finance an expansion in investment and production. Rising income and demand of both agents triggers a bid-up of land prices, and more so under higher initial

[6]Equation (21) implies that the probability of a new innovation due to R&D is decreasing in the current capital stock, so that over-investment in physical capital in the aftermath of the shock leads to a decline in the rate of technological progress

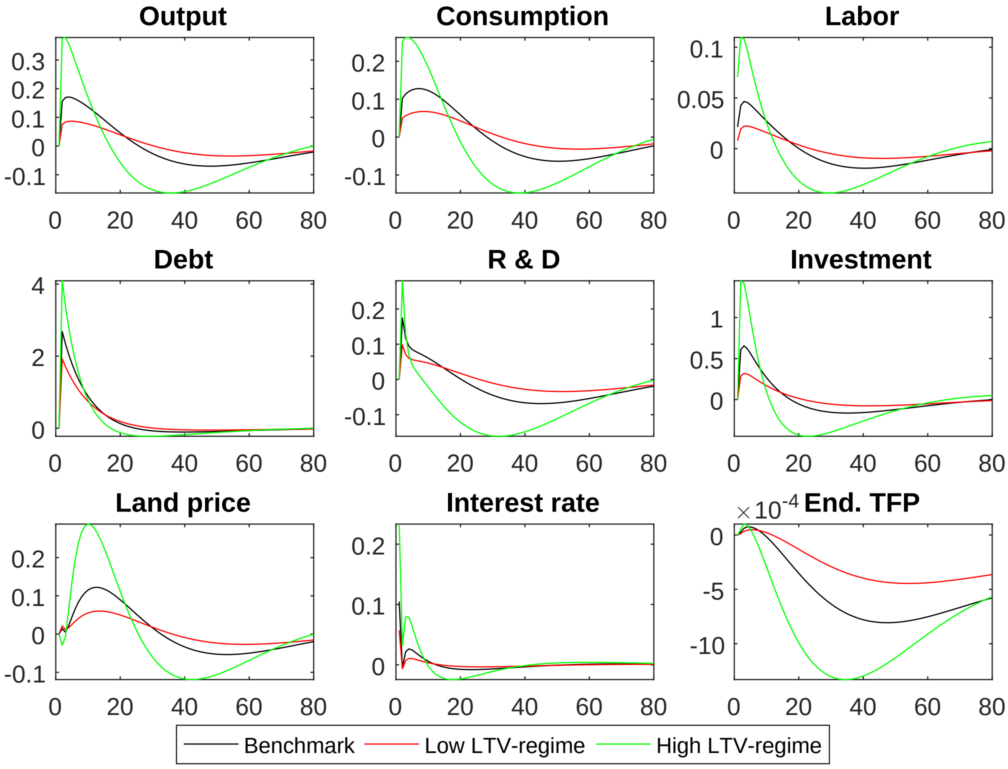

Figure 2: Impulse responses to a one standard deviation credit shock θ_t for different initial values of the LTV ratio: 0.7 (Benchmark), 0.55 (Low), 0.85 (High).

LTV ratios. Rapidly increasing leveraged borrowing leads to an economic boom which is more intense and shorter, and the consequences of the ensuing bust are more severe, the higher the initial LTV ratio. By the same token, under looser initial credit conditions, entrepreneurs' savings are promptly diverted from R&D, thus causing the accumulated technology level to decline below its pre-shock trend both over the medium and the long term; the effect is larger than that observed in the case of a land demand shock, but still small in absolute terms. These results are consistent with recent findings by Jordà et al. (2015) and Brunnermeier and Schnabel (2015) that the interaction between asset prices and credit growth poses the gravest risks to financial stability, as the damage done by the collapse of credit-fueled (housing) bubbles[7] tends to be particularly severe and long-lasting. Indeed, not only credit shocks are associated in the present model with larger fluctuations, as is clear from comparing figures (1) and (2), but the (negative) effects on output and aggregate consumption are still visible 200 periods after the shock, while they are almost completely canceled out in the case of a land-demand shock.

Moreover, the length of expansionary phase of the cycle is about 6 years, consistently with the results of Mendoza and Terrones (2012).

TFP shock Figure 3 shows that credit constraints also propagate the effects of a TFP shock in the present setting, in contrast to Liu et al. (2013)'s model, where the shock

[7]Although this model is not equipped to describe actual asset price bubbles, since it is linearized around a deterministic steady-state, it can generate bubble-like booms featuring large, self-sustained increases in the asset price eventually resulting in its collapse.

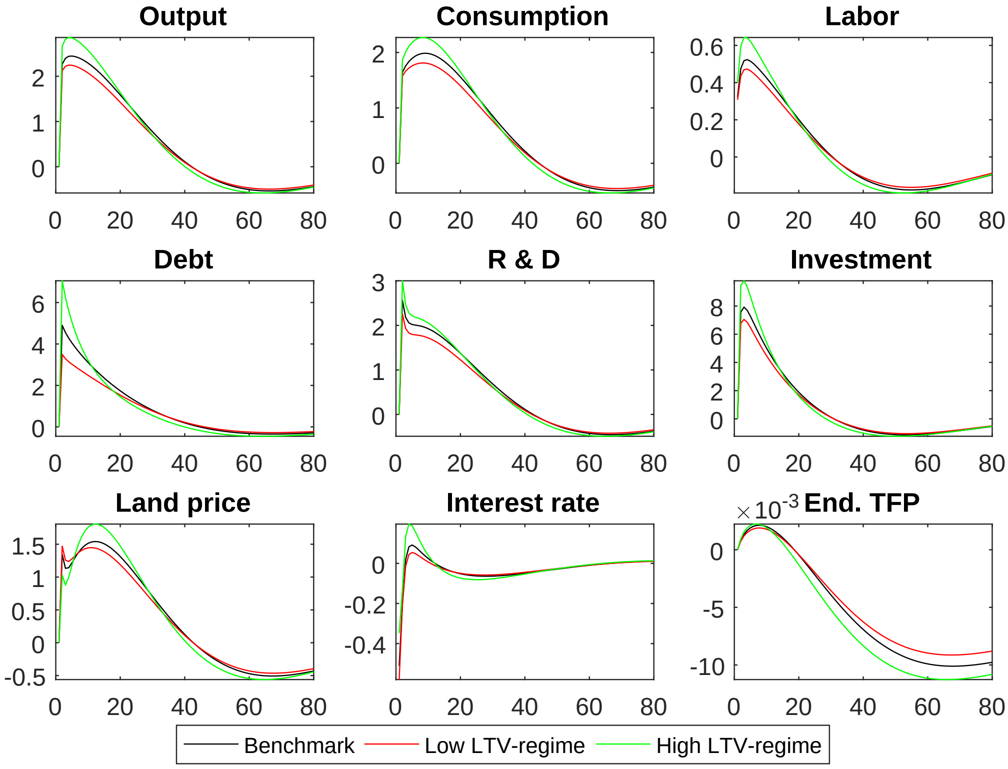

Figure 3: Impulse responses to a one standard deviation productivity shock Z_t for different initial values of the LTV ratio: 0.7 (Benchmark), 0.55 (Low), 0.85 (High).

has no sizable effect on land prices. This difference is mainly due to the lender's utility specification assumed here that reducing the wealth effect on labor supply increases the response of output and hours to technology shocks. When the economy is hit by a technology shock, the entrepreneurs raise their demand for assets, the marginal productivity of which has increased. This is especially true with respect to land, whose value as a collateral asset will permit the easing of the borrowing constraint. The incentive to invest is reinforced by having assumed habit formation on the entrepreneurs' side, which increases their marginal propensity to save after a positive TFP shock.

This induces a wide reallocation of resources from the households/lenders to the entrepreneurs/borrowers who make the production decisions, thus leading to a large output expansion. The increase in production possibilities will in turn stimulate the households' demand for consumption and housing, which will start pushing up land prices. When the economy enters its downward phase, declining returns on investment and consumption habit cause entrepreneurs' consumption to adjust too slowly, thus leading to insufficient savings. Coupled with the decrease in land prices, which reduces access to credit for the entrepreneurs, this protracts the downturn, so that the level of economic activity eventually slips below its steady-state growth trend around a decade after the shock. The dynamics of the endogenous component of TFP exhibit an initial increase following a boom in R&D activities, before starting a long decline due to the initial difficulty of developing new innovations, followed by declining output and profits.

IST shock Figure 4 describes the consequences of shocks to the investment-specific technology. Due to its effect on the probability of making a new discovery –equation (21)– such shocks increase the expected monopoly profits for the new incumbent in a sector, thus stimulating more investment in R&D. Therefore, the initial effect is a surge in R&D and, to a lesser extent, land investment (necessary to increase borrowing in the following periods), which is paid for by the entrepreneurs by reducing capital accumulation. The net impact effect of such reallocation of resources between alternative investment opportunities is slightly negative; it will take a few periods before increased R&D spending begins to pay results and output starts growing, driven by productivity gains.

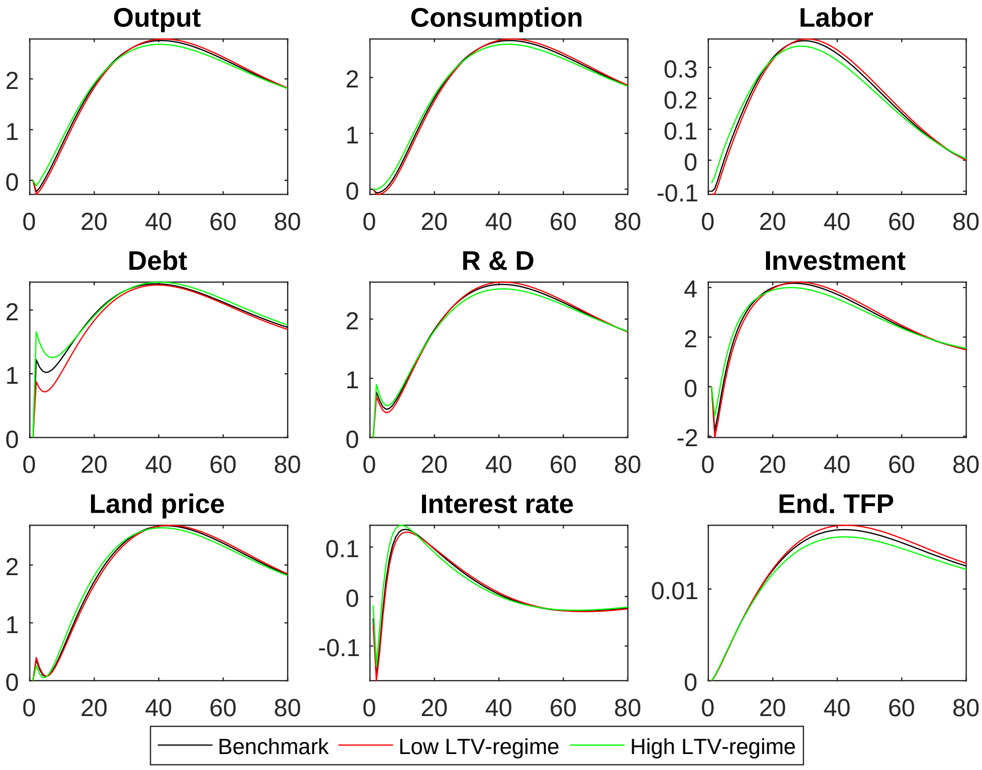

Figure 4: Impulse responses to a one standard deviation investment-specific technology shock Q_t^k for different initial values of the LTV ratio: 0.7 (Benchmark), 0.55 (Low), 0.85 (High).

Without an initial boom like those observed in response to financial or TFP shocks, households' demand remains stable during the initial periods, thus failing to inject the upward spiral of land prices. In fact, the dynamics of land prices simply mirrors the general economy, so that shocks to Q^k are not amplified through credit constraints. As IST shocks affect both the determinants of growth in the model –capital efficiency in equation (8) and innovation growth indirectly through (21)–, the final effect is a large and permanent increase in the level of economic activity and other macroeconomic aggregates.

3.3 Relative importance of the shocks

This section examines the relative importance of the shocks in driving fluctuations in several key macroeconomic variables under our benchmark calibration. In order to do so, I follow Jensen et al. (2015) in defining, for each variable F, the relative contribution of a shock π to its variance as:

$$V(F,\pi) = \frac{var(F) - var(F)_{-\pi}}{4var(F) - \sum_{\pi} var(F_{-\pi})},$$

where $\pi = \theta, \chi, Z, Q^k$, and $var(F)_{-\pi}$ is the unconditional variance of variable F when the shock π is turned off. Using this measure, variance decomposition is computed for output, land price, investment in R&D and capital, and labor hours across the four types of shocks considered in the model. The results are reported in table 3.

Table 3: Variance decomposition (%)

Variable	Shock			
	Collateral	Land demand	TFP	IST
Output	39.15	24.75	23.73	12.37
Land price	46.32	16.69	23.31	13.68
Capital Investment	29.23	47.92	12.47	10.38
R&D Investment	14.84	59.02	19.99	6.14
Hours	34.05	39.95	10.68	15.33

This table reports the contribution of the different shocks to the variance in the growth rates of output, land prices, capital and R&D investment, and working hours.

Financial shocks, by affecting firms' access to credit, emerge in the present model as the major driver of fluctuations. Together, they account for 63% to 77% of fluctuations in each of the variables considered. Specifically, collateral shocks are the main determinant of land price volatility. Since land prices directly impact upon the entrepreneur's borrowing capacity, such shocks turn out to be the single most important driver of output volatility and a significant driver of fluctuations in labor hours, capital and, to a lesser extent, R&D investment.

Likewise, a shock to households' preference for land explains a sizable fraction of output volatility as it is also propagated through the credit constraint. However, the effect on the borrowing constraint is indirect, following a land demand shock: this explains the counterintuitive result that land demand shocks account for a relatively small fraction of variation in land prices and suggests that these are driven more by entrepreneurs' demand than by the households'. In addition to this financial channel, we have seen that in the aftermath of a land demand shock the entrepreneurs use revenues from land sales to increase their demand for investment and labor. As a result, such shocks cause a substantial fraction (between 40% and 59%) of fluctuations in labor hours and investment.

Shocks to total factor productivity account for a relevant fraction (about 23%) of fluctuations in output as well as of land price volatility, in contrast to Liu et al. (2013), where TFP shocks are not propagated through the credit constraint. Moreover, TFP shocks contribute little (about 10-12%) to variation in hours and capital investment but account for a larger fraction of R&D investment (20%), since in the present setting a TFP shock raises the innovators' expected profits, thus providing a strong incentive to increase R&D.

Finally, IST shocks contribute little to fluctuations in R&D but play a larger role in explaining the volatility of output, hours, land price, and capital investment (between

10% and 15%). This result is consistent with the findings of Greenwood et al. (2000), who report that, in their calibration, IST shocks account for about 10 percent of the variance of output, and with recent DSGE literature showing that the contribution of IST shocks to output volatility is diminished in the presence of financial frictions[8].

3.4 Sensitivity analysis: excluding investment-specific technical change and introducing CRRA preferences

This section is concluded with a brief examination of two alternative specifications of the model: one that abstracts from IST change, and one where constant relative risk aversion (CRRA) preferences are introduced for both agents. The corresponding calibration and impulse responses are reported in Appendix B.

Investment-specific technological change is introduced in the present framework in order to account for the finding by Greenwood et al. (1997) that it explains close to 60 percent of the growth in output per hours worked, with residual, neutral productivity change accounting for the remaining 40 percent. If we abstract from that, economic growth would be entirely explained in the present model by R&D-led neutral productivity growth, which may lead to an overestimation of the long-run effects of shocks that impact on investment allocation, causing fluctuations in R&D investment. This could lead to a miscalculation of the effects of stabilization policies as well. Moreover, introducing IST change improves the capacity of the model to match the data, especially those on investment spending. Table 5 shows that similar calibration results can be obtained, indeed, even abstracting from IST progress, but this requires assuming a higher (4.1%) quarterly capital depreciation rate. With a lower depreciation rate, the model would exhibit excessive steady-state capital stock and investment volatility.

When we exclude IST change from the analysis, the model response to exogenous shocks (Figures 8 and 9) is almost identical to the benchmark model, except for the dynamics of the endogenous component of TFP. Indeed, in the benchmark model, IST progress has a positive effect on the probability of a new discovery; excluding IST change implies that increases in the capital accumulation rate, not matched by proportional increases in R&D, result in a larger and more persistent decrease in the aggregate rate of innovations. In the long run, this results in lower levels of output, consumption, and investment.

Appendix B also reports the results obtained when CRRA preferences are adopted. Specifically, I am assuming:

$$U_t^h = \frac{\left(C_t^h (1 - N_t)^{\varsigma} (L_t^h)^{\chi}\right)^{1-\sigma} - 1}{1 - \sigma}, \tag{30}$$

for the households, and

$$U_t^e = \frac{\left(C_t^e - \rho_e C_{t-1}^e\right)^{1-\sigma} - 1}{1 - \sigma}, \tag{31}$$

for the entrepreneurs. In order to assess whether, and if so, to what extent, our results are determined by having assumed a logarithmic utility function, I will consider

[8]Among these works, Christiano et al. (2014), Merola (2015), and Kamber et al. (2015). Earlier estimates, for instance by Fisher (2006), Justiniano et al. (2010), Schmitt-Grohe and Uribe (2012) found IST shocks to be a major driver of output and investment fluctuations.

two alternative values for the risk aversion parameter: $\sigma = 1$ and $\sigma = 2$. Table 5 shows that, with CRRA preferences, the model overestimates the volatility of R&D and (to a lesser extent) consumption growth, together with a worsening in the capacity to replicate the correlation results. Moreover, in order to match the autocorrelation of output growth, higher values of the persistence parameters in the exogenous shock processes $(\rho_\theta, \rho_X, \rho_Z, \rho_Q)$ need to be assumed. At the same time, assuming CRRA preferences may result in a better fit to the observed volatility of land price and labor growth as well as to the co-movement between R&D and output growth.

Figure 8 shows that impulse responses to TFP and credit shocks exhibit similar dynamics under the two values of σ. In both cases, the CRRA utility specification is associated with less intense initial booms followed by a smoother decline and difficulty generating hump-shaped dynamics as in the benchmark model. This result is largely explained by the different dynamics of labor hours, which represents the main difference between the benchmark model with JR preferences and the model with CRRA utility when $\sigma = 1$. Indeed, output and hours rise substantially more, and more persistently, in the benchmark model. In the case of a land-demand shock (Figure 9), log-utility leads to a large and persistent output expansion, as in the benchmark, made possible by a larger, debt-funded jump in investment. Over the medium term, however, the model with CRRA preferences invariably exhibits a smoother return to the balanced growth path, thus reinforcing the intuition that the assumption of a utility specification with a weak wealth effect on labor supply accounts well for our results, especially the occurrence of boom-bust cycles.

4 Introducing macroprudential policy

This section investigates the implications of adopting a Taylor-type rule for the loan-to-value ratio as a macroprudential policy tool. The LTV ratio will be allowed to vary in a counter-cyclical manner around its steady state value assumed in the previous section, according to the rule defined by equation (10). As possible indicators of financial conditions, I will use the growth rate of land prices and credit growth. In order to understand the functioning of a dynamic counter-cyclical LTV ratio requirement, I begin with comparing the impulse responses generated when the collateral requirement responds to one variable at a time and with assuming a coefficient in the LTV rule of 1.5. I am leaving unchanged the degree of persistence (0.9) of changes in the LTV ratio in order to maintain comparability with the effects of an AR(1) shock to credit conditions, described in the previous section.

Impulse responses Figures 5 and 6 illustrate the model response to financial shocks under the different specifications of the LTV rule. In general, dynamic LTV requirements seem capable of mitigating output volatility following a shock to credit conditions[9] or to land demand, although the effectiveness crucially depends on the source of the shock as well as on the variable targeted.

Indeed, as figure 5 shows, an LTV rule that responds to changes in output or credit growth attenuates, and even prevents in the case of the rule targeting credit, the strong

[9]Bear in mind that despite the LTV ratio being a policy tool, I am assuming that it can be subject to exogenous shocks that affect the entrepreneur's funding conditions against unchanged collateral values, due, for instance, to financial innovations originating in the private sector.

relaxation of the collateral constraint stemming from an upward pressure on land prices. The resulting stabilization of the real interest rate helps stabilize the lenders' consumption demand by reducing the volatility of interest income. On the Borrowers' side, the initial increase in land holdings is broadly similar across all cases except the rule targeting credit growth; but due to the weaker household demand, there is less pressure on land prices, whose oscillations will be less pronounced than in the benchmark case. In turn, the reduced volatility of land prices helps stabilize investment, by reducing the uncertainty about access to financing. Hence, such a policy is successful in limiting the amplification effect of the credit constraint in response to a collateral shock, leading to an expansionary phase of the cycle which is less intense, but longer. This is especially true in the case of an LTV rule targeting credit growth which, by preventing the initial boom in credit availability, is particularly effective at reducing the volatilities of output and other macroeconomic aggregates - and especially of R&D investment, which results in a more favorable dynamics of TFP.

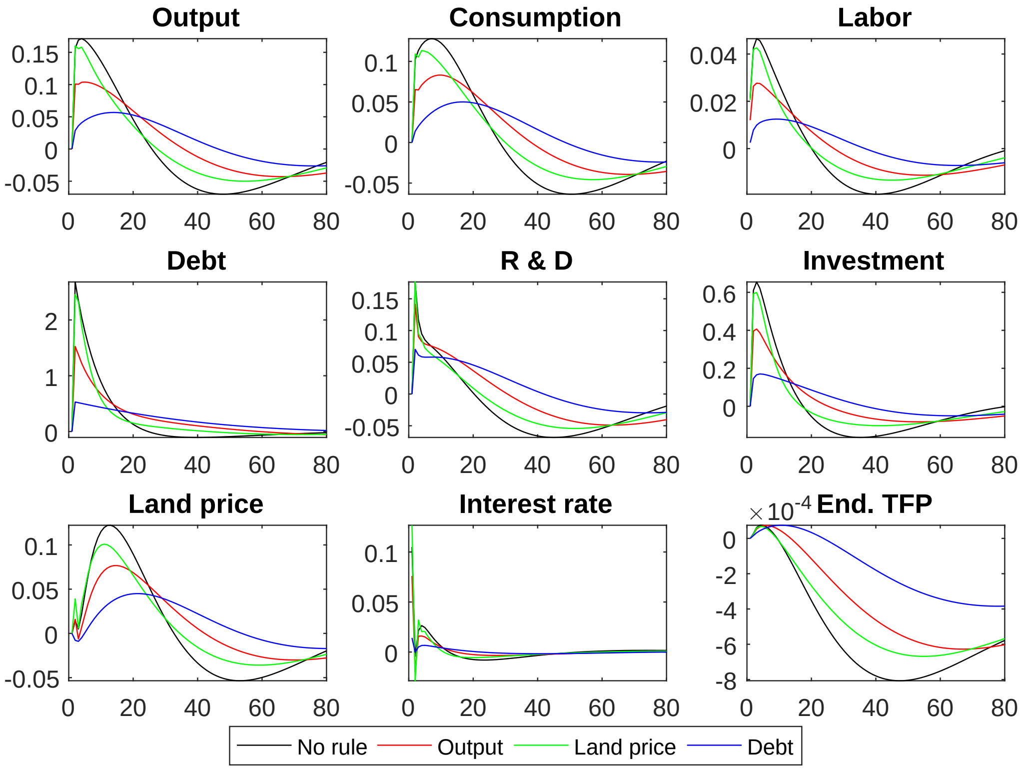

Figure 5: Impulse responses to a credit shock θ_t under simple policy rules targeting output growth, land price growth, or credit growth.

When the LTV rule reacts to changes in land price growth, Borrowers increase their demand of land on impact, as they anticipate the credit tightening that will come with the rise of prices. This leads the interest rate to peak on impact and to fall afterward, depressing the interest income of the households. Thus, as both agents cut back on spending (although lenders will keep buying back land for a while, prompted by still-increasing land prices), the economy will begin slowing down earlier (compared to all alternative scenarios) and less severely, compared to the benchmark where the LTV rule is not in place.

The effects of a counter-cyclical LTV requirement are somewhat different when the economy is hit by a shock to land demand, due to the different dynamics of credit to the entrepreneurs. Indeed, since Savers reduce the concession of loans to entrepreneurs in response to the shock, an LTV rule that targets credit growth relaxes the borrowing constraint, and thus improves Borrowers' ability to invest in housing even as the economy is expanding. Hence, such a policy ends up strengthening the amplification effect of credit constraints in response to a land demand shock.

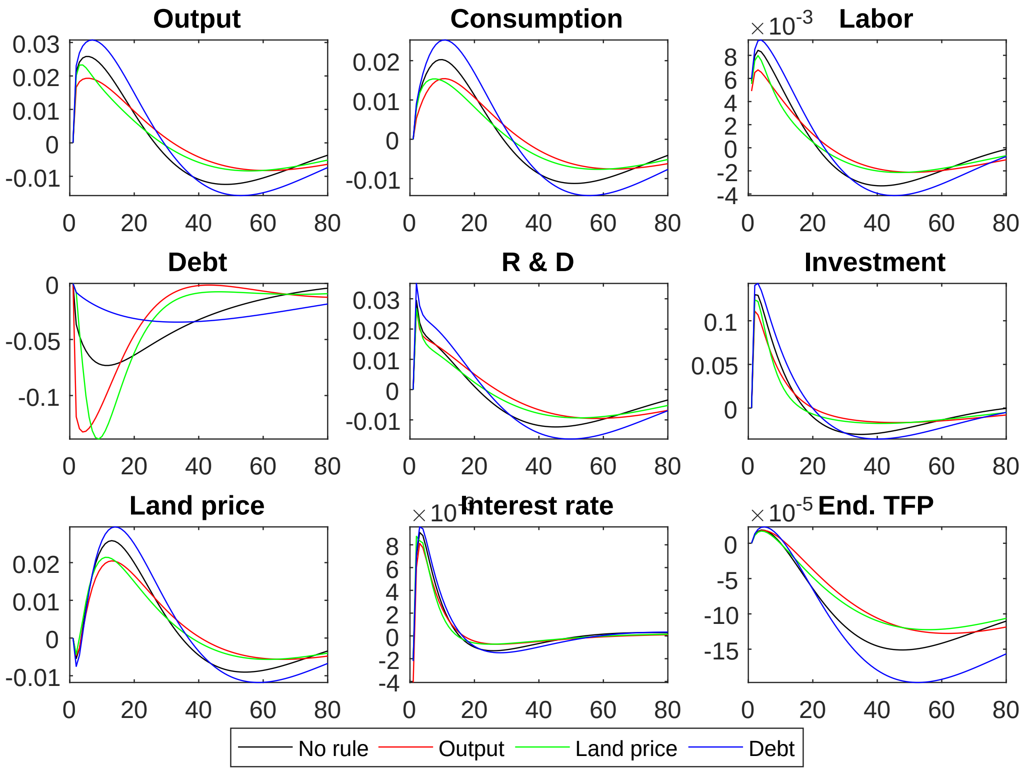

Figure 6: Impulse responses to a land demand shock χ_t under simple policy rules targeting output growth, land price growth, or credit growth.

Conversely, a policy rule that responds to changes in land prices or output growth is more effective in reducing the volatility of investment, due to reduced access to credit. As for the Savers, the stronger credit tightening, in spite of an analogous interest rate dynamics across all the alternative scenarios, results over the medium term in a particularly pronounced decline of interest income and, hence, of household's demand. As is the case with the collateral shock considered above, the LTV rule that targets land prices is associated with a shorter expansionary phase. As the land price declines on impact, the initial effect is similar to the benchmark case where the rule is not active; then, as land prices rise and the LTV rule comes into effect, tightened access to credit induces Borrowers to reduce investment, while lenders cut on their consumption spending due to declining interest income. As a consequence, the economy begins slowing down one year after the shock, and the decline is more persistent than under the alternative specifications of the rule, although it is, again, less severe.

When the economy is hit by a TFP shock (fig. 7), LTV rules reduce the volatility of both investment and household consumption; when land prices or credit are targeted, they also reduce the volatility of loans to entrepreneurs. The stabilization effect is even stronger when the rule responds to changes in the output growth rate. In fact, the large credit tightening that follows a TFP shock leads Borrowers to sell part of their land holdings, which now have lost their collateral value; this prevents a boom in land prices, thus restricting significantly the amplification of the shock.

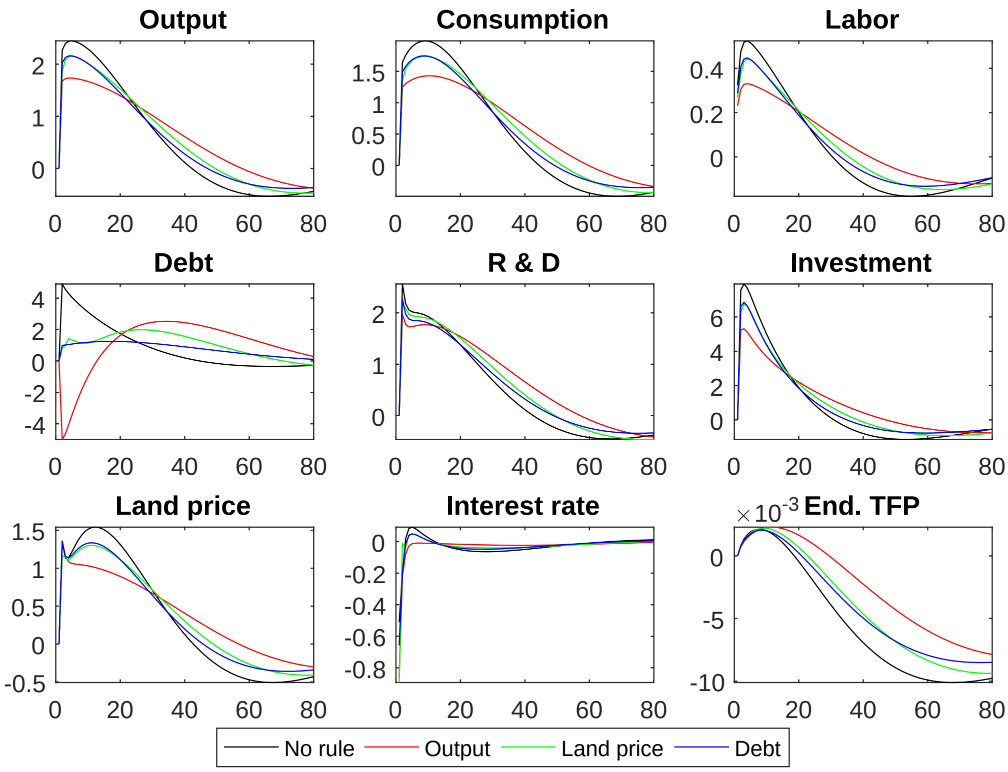

Figure 7: Impulse responses to a productivity shock Z_t under simple policy rules targeting output growth, land price growth, or credit growth..

Finally, figure 10 in the appendix shows that the effects of an LTV rule are small when the economy is hit by a shock to the investment-specific technology, as we might expect since we have seen that the credit constraint has no amplification effect in this case. Despite the different responses of credit to entrepreneurs, all the considered policies (and more so when the LTV ratio reacts to output growth) lead to a smoother and more persistent increase in output, consumption, and investment.

Optimal policy In what follows, I calculate the optimal macroprudential policy, that is, the reaction parameters (ρ_y, ρ_q) of the macroprudential rule that maximize welfare, at both the individual and the social level, and compare the macroeconomic volatilities resulting under the corresponding alternative specifications of the rule.

Individual welfare for Savers (V_h) and Borrowers (V_e) is measured as the expected lifetime utility at time t, that is:

$$V_{h,t} = E_t \sum_{s=0}^{\infty} (\beta^h)^s U_h(C^h_{t+s}, N_{t+s}, L^h_{t+s}), \tag{32a}$$

$$V_{e,t} = E_t \sum_{s=0}^{\infty} (\beta^e)^s U_e(C^e_{t+s}). \tag{32b}$$

Social welfare is defined as the weighted average of the welfare of the two agents. That is, following Mendicino and Punzi (2014):

$$V_{S,t} = (1 - \beta^e)V_{e,t} + (1 - \beta^h)V_{h,t}. \tag{33}$$

Following a common approach in DSGE literature, I compute the welfare levels implied by the alternative rules by using a second-order approximated solution to the structural equations under each given policy. To do so, I search over a grid, with the range for the reaction parameters being [0,10], and setting the grid step to 0.1. The alternative welfare-maximizing rules are compared both in terms of levels of welfare and in terms of consumption equivalents, that is the percentage increase in individual steady-state consumption that would make the welfare of each agent under the benchmark economy, where macroprudential policy is not active, equal to welfare under the optimized rule.

Table 4 reports the optimizing reaction coefficients for the rule responding to credit growth, and the corresponding results in terms of welfare and volatility of some key variables. The main results can be summarized as follows: (a) welfare is maximized under a rule that reacts to deviations of credit growth from its steady-state value; (b) rules that respond to output or land price growth are not welfare-improving; (c) strong reactions of the LTV ratio are in general desirable, although a stronger reaction is preferred by Borrowers, while a milder one would leave Savers better off; (d) macroprudential policy can result in substantial stabilization effects, but the associated welfare gains are small, between 0.07% and 0.2% in consumption equivalent terms.

Table 4: Welfare and volatility effects of Macroprudential policy

		Reaction coefficients		
		$\rho_q = 1.9$	$\rho_q = 10$	$\rho_q = 6.6$
Welfare	Borrower's gains (%)	0.08 (0.06, 5.61)	0.06 (0.07, 3.17)	0.07 (0.06, 4.42)
	Saver's gains (%)	0.15 (0.17, 11.08)	0.20 (0.21, 9.06)	0.19 (0.20, 10.20)
	Social (Benchmark:-3.8524)	-3.8501	-3.8499	-3.8498
St. Dev.	Output	1.87	1.83	1.84
	Consumption	1.32	1.30	1.30
	Interest rate	0.42	0.42	0.42
	Investment	9.25	9.26	9.26
	R&D	4.68	4.75	4.73
	Land price	1.98	1.97	1.97

The top side of the table shows simulated social welfare levels and individual consumption-equivalent welfare gains w.r.t. the benchmark, where the LTV rule is not active, under optimal LTV response to credit growth for each agent and for social welfare. In the parenthesis are reported welfare gains obtained, respectively, for the model without IST progress, and with CRRA preferences. The bottom side of the table shows the corresponding volatility results for selected variables in the benchmark model.

Consistent with our aforementioned findings, LTV ratios that optimally respond to credit growth reduce the volatility of both household credit and land prices. Indeed, although the amplification effect of credit constraints in response to a land demand shock is strengthened under such a rule, we have seen that land demand shocks explain a smaller fraction of fluctuations in output and land prices. The reduction in the volatility of land prices reduces the uncertainty about the access to financing. This helps Borrowers smooth consumption and land investment over time and improves their welfare.

The stabilization of the real interest rate reduces the volatility of the households' interest income, thus helping to stabilize their housing investment and consumption over the cycle. By mitigating boom-bust cycles, this policy is therefore welfare-improving for both agents, although the Saver's welfare increases in direct relation to the LTV reaction to credit growth, while the Borrower's welfare is maximized under a reaction parameter equal to 1.9.

Despite strong stabilization effects, such policies do not result in significant welfare gains. In fact, evaluating welfare ultimately involves taking into account both volatility gains and changes in the variables' levels, which are small over the long term. Alternative rules, particularly those targeting output growth or both output and credit growth, are even more effective in stabilizing the economy than the LTV rule considered above, but they are not associated with any welfare gains in the present setting. Finally, table 4 also reports welfare results for the model without IST progress and the model with CRRA (with $\sigma = 2$), under the same values for the reaction coefficients. It shows that welfare gains are of the same order of magnitude in the first case, while they are significantly larger in the second[10]. The different dynamics of labor supply in response to shocks contribute to explaining this result. Indeed, under CRRA preferences, the introduction of a macroprudential policy rule induces a significantly larger increase in leisure time, in the aftermath of TFP and credit shocks, compared to the benchmark.

5 Conclusion

This paper has studied a DSGE model that incorporates endogenous Schumpeterian growth and land, used by firms as a collateral asset to finance investment spending. It shows that financial shocks which affect firms' access to credit either directly, like an exogenous change in the LTV ratio, or indirectly, like a change in the households' taste for land that impacts on the valuation of the collateral asset, can generate boom-bust cycles featuring large fluctuations in land prices, consumption, and investment. Technology shocks also generate a similar dynamics in this framework, although the results suggest that a relaxation of the collateral constraint is more likely to produce fluctuations like those observed in the years around the Great Recession. The results also indicate that during the expansionary phase of the cycle, rising land prices tend to crowd out capital and (especially) R&D investment, consistent with the findings of Cecchetti and Kharroubi (2015) and Borio et al. (2016). This effect is stronger under looser initial credit conditions.

In the context of this model, I also explore the stabilization effects of LTV-ratio policies which target output growth and financial variables. This is done in an endogenous growth framework, where exogenous shocks, and hence even more so stabilization policies, can have permanent effects with relevant consequences for welfare evaluation. In this respect, I find that a counter-cyclical LTV ratio that responds to credit growth has relevant stabilization effects but yields minimal welfare gains. Alternative rules that tar-

[10]The reaction coefficients are optimally chosen for the benchmark model; thus, in both the alternative cases, welfare-maximizing rules would probably lead to larger welfare gains.

get output or land prices would be effective in stabilizing the economy but would not be welfare-improving.

However, the present framework does not include nominal rigidities. When these are introduced together with endogenous real interest rates, monetary policy can become constrained at the zero lower bound when the economy is hit by a severe crisis, and the associated welfare costs could be higher. Hence, welfare gains from stabilization policies could also turn out to be larger. Such assumptions would also permit the investigation of the combined effect of monetary and macroprudential policies. This is the subject of a growing literature, but whether or not monetary policy should pursue financial stability objectives remains an open question.

A less-explored path is the coordination between fiscal and macroprudential policies. On this issue, Bianchi and Mendoza (2011, 2015) and Jeanne and Korinek (2010) investigate the effects of Pigouvian taxes on debt, while Pintus and Wen (2013) show that (high enough) consumption taxes can have strong stabilization effects. In a setting without credit frictions, Nuño (2011) shows that combined subsidies on capital accumulation and R&D can generate large welfare gains by restoring the optimal investment allocation. To the extent that such measures can counteract resource misallocations, these could also help stabilize the economy. This is a promising direction for further research.

Moreover, a different utility specification, such as in Epstein and Zin's (1989) preferences or additional frictions, may be needed to account for the volatility of land prices (the present framework accounts for only half of that). For example, introducing credit-constrained households as in Iacoviello (2005) or Jensen et al. (2015) would probably increase the volatility associated with shocks to housing preferences.

Finally, it is worth considering alternative policy tools such as reserves and capital requirements, perhaps in combination with some insurance tools, against the fallout from a house-price bust. Mandatory Mortgage Default Insurance, required in Canada for borrowers with mortgages above 80% of the collateral value, is an example of such a tool. These issues are left for further research.

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Appendix

A Equations of the stationary model

In order to describe the dynamics of the model around a balanced growth path, the growing variables are transformed to make the model stationary. In general, I define a variable $f_t \equiv F_t/\Gamma_t$ as the detrended version of variable F_t, where $\Gamma_t \equiv A_t^*(Q_t^k)^{\frac{\alpha}{1-\alpha}}$. Moreover, I define the following transformed variables:

$$a_t \equiv \frac{A_t}{A_t^*}; \qquad k_t \equiv \frac{K_t}{Q_t^k \Gamma_t}; \qquad i_t \equiv \frac{I_t}{Q_t^k \Gamma_t}; \qquad \lambda_t^{e,h} \equiv \Lambda_t^{e,h}\Gamma_t; \qquad \phi_t^b \equiv \Phi_t^b \Gamma_t; \qquad q_t^k \equiv Q_t^k(\frac{\Phi_t^k}{\Lambda_t^e}).$$

Hence, the model is described by the following set of stationary equilibrium equations[11]:

$$w = \frac{\zeta\kappa p N^{\zeta-1}}{(\lambda^h((c^h - \rho_h c_{t-1}^h)/g) - \kappa p N^\zeta)}; \tag{A-1a}$$

$$N = (1-\alpha-\gamma)y/w; \tag{A-1b}$$

$$k = \frac{(1-\delta)k_{t-1}}{gg_q} + (1 - \frac{O}{2}(\frac{i}{i_{t-1}}gg_q - g_k)^2)i; \tag{A-1c}$$

$$\begin{aligned} 1 = {} & q^k(1 - \frac{O}{2}(\frac{i}{i_{t-1}}gg_q - g_k)^2 - O(\frac{i}{i_{t-1}}gg_q - g_k)\frac{i}{i_{t-1}}gg_q) \\ & + \beta^e q_{t+1}^k \frac{\lambda_{t+1}^e}{\lambda^e g_{t+1}g_{q,t+1}} O(\frac{i_{t+1}}{i}g_{t+1}g_{q,t+1} - g_k)(\frac{i_{t+1}}{i}g_{t+1}g_{q,t+1})^2; \end{aligned} \tag{A-1d}$$

$$g_a = 1 + \epsilon n_{t-1}; \tag{A-1e}$$

$$g = g_a g_q^{\alpha/(1-\alpha)}; \tag{A-1f}$$

$$x = \psi k n^{1+\eta}; \tag{A-1g}$$

$$y = ZN^{1-\alpha-\gamma}a^{1-\alpha}(L_{t-1}^e)^\gamma(\frac{k_{t-1}}{gg_q})^\alpha; \tag{A-1h}$$

$$a = \frac{(n_{t-1}(1-a_{t-1}) + a_{t-1})}{g_a}; \tag{A-1i}$$

$$y = c + i + x; \tag{A-1j}$$

$$x = \frac{n}{1+\eta}\beta^e \frac{\lambda_{t+1}^e}{\lambda^e}\frac{v_{t+1}}{g_{a,t+1}}; \tag{A-1k}$$

$$\mu = \alpha^2 gg_q \frac{y}{k_{t-1}}; \tag{A-1l}$$

$$v = \alpha(1-\alpha)\frac{y}{a} + (1-n)\beta^e * \frac{\lambda_{t+1}^e}{\lambda_e}\frac{v_{t+1}}{g_{a,t+1}}; \tag{A-1m}$$

$$q^l = \beta^e \frac{\lambda_{t+1}^e}{\lambda_e}(\gamma\frac{y_{t+1}}{L^e} + q_{t+1}^l) + (\frac{\phi^b}{\lambda^e})\theta q_{t+1}^l g_{t+1}; \tag{A-1n}$$

$$1 = \beta^e \frac{\lambda_{t+1}^e}{\lambda_e}\frac{R}{g_{t+1}} + \frac{R\phi^b}{\lambda^e}; \tag{A-1o}$$

[11] For simplicity of notation, the time index is omitted for variables at time t.

$$1 = \beta^h \frac{\lambda^h_{t+1}}{\lambda_h} \frac{R}{g_{t+1}}; \tag{A-1p}$$

$$\lambda^e = \frac{1}{c^e - \rho_e c^e_{t-1}/g}; \tag{A-1q}$$

$$\lambda^h = \frac{1}{c^h - \kappa p N^\zeta - \xi \nu p / c^h}; \tag{A-1r}$$

$$q^l = \frac{\chi}{\lambda^h L^h} + \beta^h \frac{\lambda^h_{t+1}}{\lambda_h} q^l_{t+1}; \tag{A-1s}$$

$$c^h = wN - q^l(L^h - L^h_{t-1}) - \frac{b}{R} + \frac{b_{t-1}}{g}; \tag{A-1t}$$

$$b = \theta q^l_{t+1} g_{t+1} L^e; \tag{A-1u}$$

$$q^k = \beta_e \frac{\lambda^e_{t+1}}{\lambda^e g_{t+1} g_{q,t+1}} (\mu_{t+1} + (1-\delta) q^k_{t+1}); \tag{A-1v}$$

$$\xi = \kappa \frac{N^\zeta}{c^h - \kappa p N^\zeta} + \beta^h (1-\nu) \xi_{t+1} p_{t+1} / p; \tag{A-1w}$$

$$p = (c^h)^\nu (p_{t-1}/g)^{1-\nu}; \tag{A-1x}$$

$$c = c^e + c^h; \tag{A-1y}$$

$$1 = L^e + L^h, \tag{A-1z}$$

plus the exogenous processes described by equations (10), (3), (8), and (14).

B Sensitivity analysis

Table 5: Alternative model calibrations

Steady-state parameters				
Parameter	Benchmark	No IST	CRRA(1)	CRRA(2)
α	0.35	0.35	0.35	0.35
γ	0.021	0.021	0.021	0.021
β^e	0.991	0.991	0.994	0.991
β^h	0.995	0.995	0.998	0.995
δ	0.036	0.041	0.036	0.036
ϵ	0.087	0.192	0.083	0.087
ζ	1.2	1.2	2.94	2.94
η	7.17	7.32	7.81	7.13
θ	0.7	0.7	0.75	0.7
ν	0.023	0.023	–	–
ρ^e	0.73	0.7	0.37	0.73
ρ^h	3.16	3.16	–	–
χ	0.052	0.052	0.056	0.044
$\log \psi$	25.46	26	27.85	25.32
O	0.374	0.37	4.5	4
Shock parameters				
σ_θ	0.029	0.029	0.045	0.05
σ_χ	0.16	0.17	0.14	0.149
σ_Z	0.0015	0.0017	0.0027	0.003
σ_Q	0.0033	–	0.007	0.008
ρ_θ	0.9	0.9	0.95	0.95
ρ_χ	0.9	0.9	0.95	0.95
ρ_Z	0.9	0.9	0.95	0.9
ρ_Q	0.66	–	0.85	0.75

Moments				
Variable	Benchmark	No IST	CRRA(1)	CRRA(2)
Annual averages				
g	1.92%	1.92%	1.78%	1.92%
i/y	10.25%	10.25%	9.91%	10.25%
k/y	56.57%	56.85%	55.69%	56.57%
b/y	60.21%	60.21%	53.52%	60.21%
L_e	37%	37%	33%	37%
R	3.9%	3.9%	4.3%	3.9%
Second order moments				
σ_y	2.38	2.38	2.38	2.38
σ_c	1.72	1.67	1.88	1.89
σ_i	10.55	10.52	10.93	10.56
σ_x	4.76	4.89	11.42	13.28
σ_{Q_l}	2.52	2.45	8.20	4.41
σ_N	2.77	2.71	2.76	3.06
$\rho_{y,c}$	0.92	0.92	0.88	0.86
$\rho_{y,i}$	0.86	0.88	0.73	0.74
$\rho_{y,x}$	0.59	0.66	0.50	0.44
ρ_{y,Q_l}	0.39	0.41	0.51	0.57
$\rho_{Q_l,i}$	0.03	0.05	0.28	0.43
$\rho_{Q_l,x}$	0.32	0.29	0.04	0.71
$\rho_{y,y(-1)}$	0.51	0.46	0.51	0.52

Calibration results (quarterly frequency) obtained under alternative model specifications: the benchmark model, the version without investment-specific technical change (No IST), the version with CRRA preferences and $\sigma = 2$ (CRRA(1)), the version with CRRA preferences and $\sigma = 1$ (CRRA(2)).

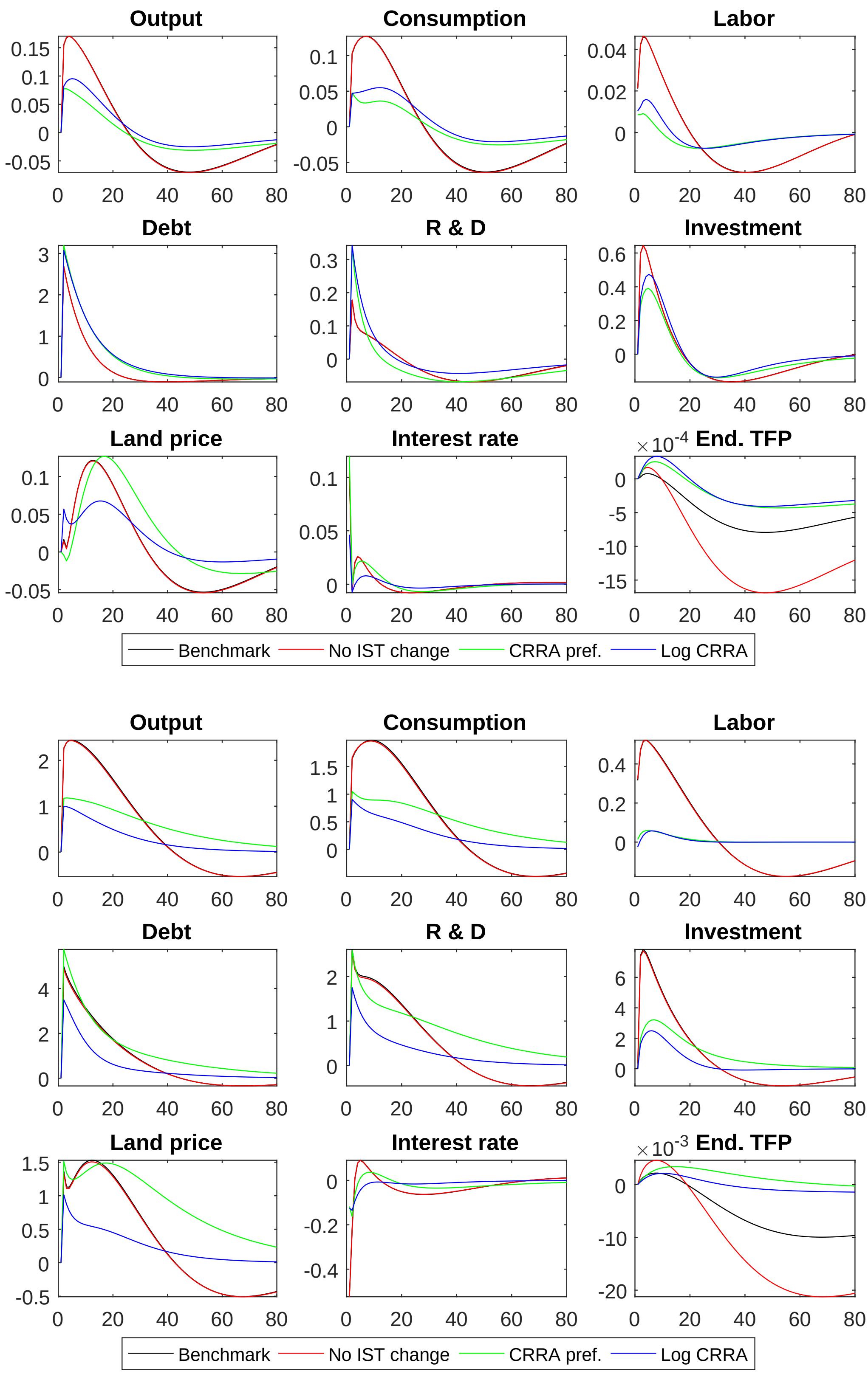

Figure 8: IRF to a Credit shock (top) and to a TFP shock (bottom) under alternative model specifications: the benchmark model, the version without investment-specific technical change (No IST), the version with CRRA preferences and $\sigma = 2$ (CRRA), the version with CRRA preferences and $\sigma = 1$ (Log CRRA).

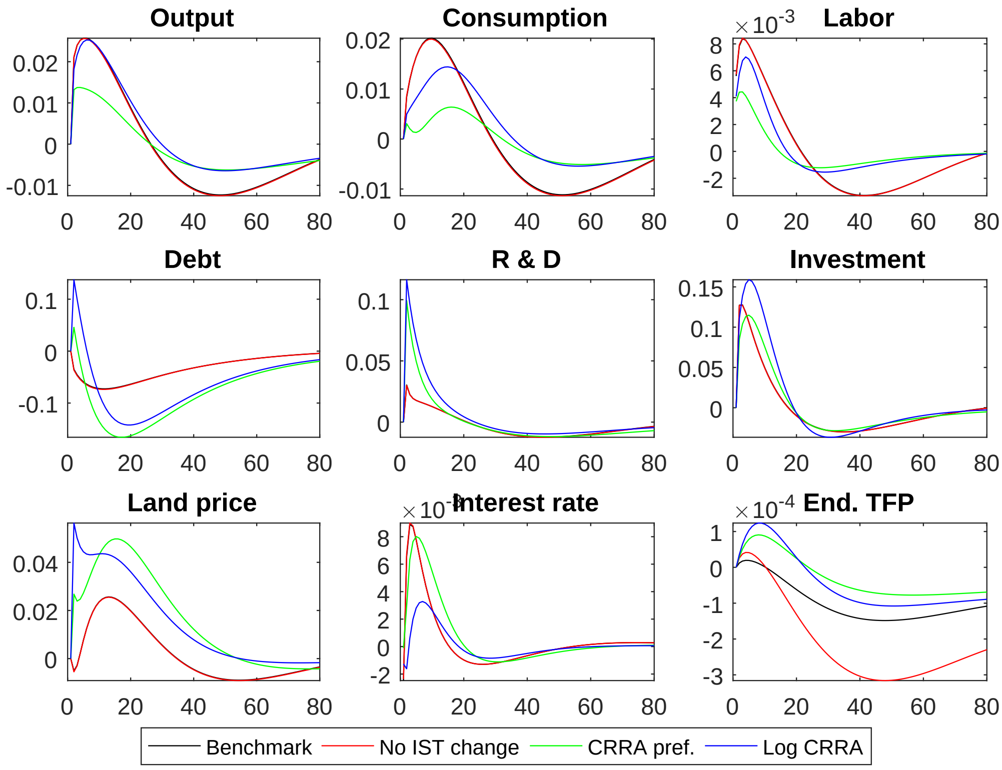

Figure 9: IRF to a Land-demand shock under alternative model specifications: the benchmark model, the version without investment-specific technical change (No IST), the version with CRRA preferences and $\sigma = 2$ (CRRA), the version with CRRA preferences and $\sigma = 1$ (Log CRRA).

C Macroprudential policy effects: IST shocks

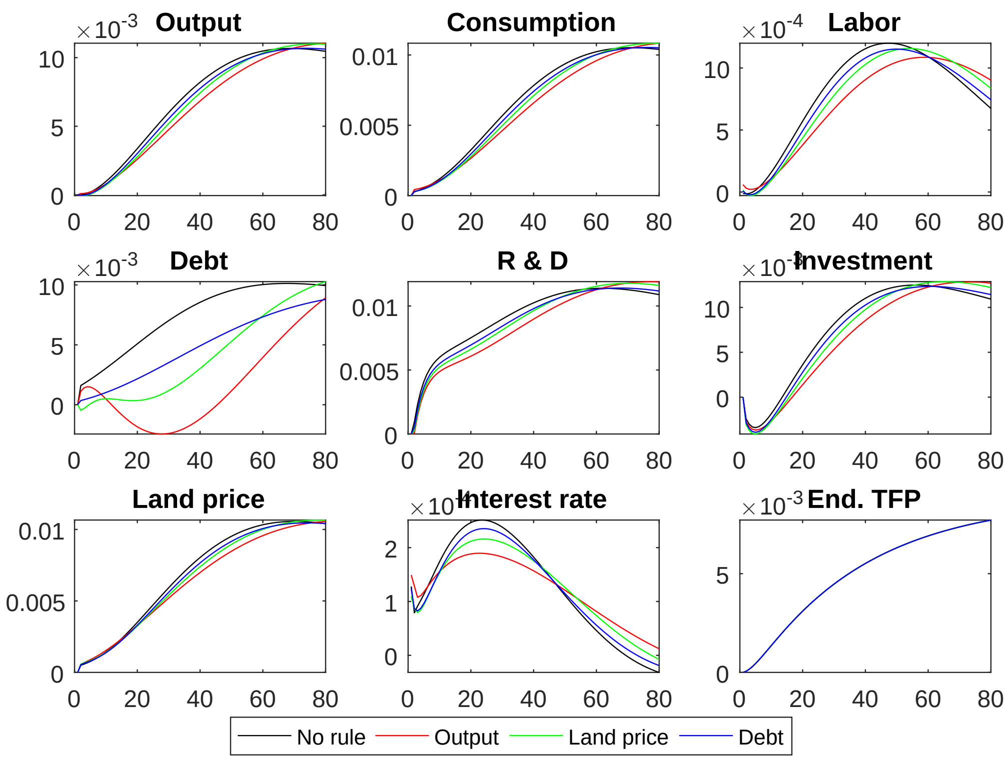

Figure 10: IRF to an IST shock under simple policy rules targeting output growth, land price growth, or credit growth.