Housing Collateral Effects: Structural Estimation and Empirical Evidence from UK

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Very preliminary, comments welcome

Abstract

The starting point is the dynamic general equilibrium model developed by Iacoviello (2005), a model with sticky prices, nominal debt and collateral constraints tied to expectations on housing values, these features of the model allow demand shocks to be amplified and propagated in the economy. In the model constructed and estimated in this paper, the well-known loan-to-value ratio is not constant but is time-variant and, in particular, its evolution depends on housing price expectations. Thus, the standard financial accelerator is amplified. The framework is calibrated to match UK economic conditions prevailing at the start of the recent sub-prime crises. An autoregressive vector and a structural autoregressive vector are estimated in order to analyse the role of the housing price in the UK economy in the last 25 years, that is to say after the UK mortgage deregulation.

Résumé

Le point de départ c'est le modèle d'équilibre général dynamique développé par Iacoviello(2005) caracterisé par des prix fixes, dette nominale et contraintes de crédit. La valeur anticipée des biens immobiliers est utilisée par les prêteurs comme garantie lors du contrat de prêt. Avec ces hypothèses les chocs de demande sont amplifiés et propagés dans l'économie. Dans le modèle construit et estimé dans cet article, le ratio *loan-to-value* n'est pas constant mais il varie au cours du temps, et en particulier, son évolution va dépendre des anticipations sur le prix des biens immobiliers. Ainsi, l'accélérateur financier standard est renforcé. La calibration du modèle est faite de manière à refléter les conditions économiques du Royaume-Uni avant la crise des *subprimes*. Une estimation VAR et SVAR est effectuée avec l'objectif d'analyser le rôle du prix des biens immobiliers dans les fluctuations de l'économie du Royaume-Uni après la dérégulation du marché hypothecaire des années 80.

I would like to thank my master thesis advisor professor Jean-Bernard Chatelain for his suggestions, availability and patience. I would like to thank also professor Ibrahim Ahamada for helpful suggestions. Overall, I am deeply indebted to all the people who help me somehow or other through the period of my economic studies in France.

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I. Introduction

The current crisis has highlighted several mechanisms that accentuate the business cycle movements [1]. Nowadays, policies to mitigate procyclicality have regained attention of researchers and policy makers.

In this paper, I focus in the procyclicality induced by the loan-to-value ratio (LTV) [2]. More precise, I study the economic consequences of the propensity of the loan-to-value ratio to rise in property boom periods and to fall when the real property price goes down.

How to attenuate the "amplificator" effects of such mechanism? Some policy measures are suggested in the literature. Recently, Goodhart *et al.* (2008) and IMF (2009) for instance, recommend to establish a countercyclical regulatory ceiling for LTV's that could be increased when real housing price growth was low or declining and lowered during booms periods. Moreover, Borio (2001) , among others, suggests to link the maximum ratio policy to other regulatory tools like capital requirements. In Table 1, I report the main policies concerning LTV ratio regulation and capital requirement regulations linked to the level of LTV ratio in different countries in the last years.

In the aim to capture the quantitative effects of this pro-cyclical behaviour, I use the Iacoviello (2005) credit constraints set-up as a benchmark framework and I extend and simulate his general equilibrium model to account for the pro-cyclical consequences of the LTV ratio in the UK business cycle.

Bernanke *et al.* (1996 and 1999), develop the New Keynesian Macroeconomic framework, where financial factors take a central role in the business cycle propagation and amplification. In the same line of research, Iacoviello (2005) construct a borrower-saver dynamic stochastic general equilibrium model with nominal debt and credit constraints. Credit constraint is considered to be an upper bound to the total amount of debt issued to an agent. The upper bound corresponds to a ratio of the value of the property prices holding by the debtors, which in case of default will be transferred to the creditor in order for the later to recover the outstanding payments.

1 Confer for instance IMF (2009) paper for a complete summary of pro-cyclical mechanisms and recommendations to alleviate their negative effects.

2 The loan-to-value ratio is a proportion of the value of the collateralized property which can be borrowed.

Table 1

LTV regulation measures

Bulgaria	2004	Introduction of a 70% LTV ratio for mortgages risk-weighted at 50%; when violated, exposures assigned a 100% risk weight.
China	2001	Reduction in maximum LTV ratio for mortgages to 80%.
	2005	Recommended reduction in maximum LTV ratio from 80% to 70% for properties in cities or regions with excessively fast housing price increase.
Croatia	2006	Introduction of maximum LTV ratio for housing loans at 75%.
Hong Kong	1991	Reduction in LTV ratio from 80-90% to 70%.
Ireland	2006	Increase in risk weight for mortgages from 50% to 100% of the loan value on the portion of each loan exceeding 80% of the value of the property as of May 2006.
Korea	2003	Reduction in LTV ratios applied to bank loans from 60% to 50% and then 40% in the geographical areas where property prices surged or were seen as likely to surge, with some exceptions.
	2006	The exceptions under 2003 measures were abolished for bank loans. Reduction in LTV ratios applied to non-bank loans from 60-70% to 50%.
Malaysia	1995 -98	Introduction of a maximum LTV ratio of 60% on real state loans (discontinued in 1998).
Norway	1998 -01	Increase in risk weight from 50% to 100% for loans with an LTV ratio above 60% (previously 80%) (discontinued in 2001).
Portugal	1999	Tighter capital requirements for housing loans with an LTV ratio exceeding 75%.
Romania	2004	Introduction of a maximum LTV ratio of 75% for mortgages.
Thailand	2003	Introduction of a maximum LTV ratio of 70%. Tighter eligibility requirements for housing loans.

Note. Selected information borrowed to Borio et al. (2007).

The mechanism of the model works as follows. If the economy is hit by a demand shock, consumer and housing prices go up. The increase in property prices relax the credit constraint of the debtors, allowing them to consume and invest more. In addition, the rise in inflation rate operate an implicit transfer from lenders to borrowers since the interest rate is fixed between the agents in nominal terms. With the further assumption that borrowers have a higher propensity to consume than lenders, the net effect on aggregate demand is positive.

In this article I sum up a supplementary amplification effect: the increase in housing price expectations raise the loan-to-value ratio, knowing that the higher is the LTV ratio, the higher is the marginal amount of new lending that can be accorded for a given change in the value of the collateral. Thus, the larger will be the effects on aggregate consumption and investment.

The article is organized as follows. Section II presents a brief description of the UK housing market. Section III shows some VAR evidence of the housing price role on the UK economy. Section IV present the general equilibrium model. Section V analyses the dynamics around the steady state of the constructed model. Finally, Section VI concludes.

II. UK housing market description

UK economy is an interesting case to study not only the link between housing price and output but also the LTV ratio procyclicality. UK mortgage market is one of the larger and more flexible market in Europe [3]. Concerning housing loans, nominal and variable interest rates are currently used. Likewise, equity withdrawal is facilitated by a large range of equity release products. Moreover, mortgage over GDP ratio (over 70%) are relatively high with respect to other continental European economies, with basically two exceptions: Netherlands and Denmark.

3 European countries with also a relatively high flexible mortgage markets are Denmark, Finland, Ireland, and Netherlands (confer Calza et al (2007) and Tsatsaronis et al. (2004) for country clustering with respect to mortgage market flexibility).

Recent studies show the large effects of housing price variation in consumption and output in UK. DSGE models of Aoki *et al.* (2004) or Hall (2003) calibrated and simulated for UK economy, report the mentioned large effects using the financial accelerator framework.

Regarding the overall LTV ratio pro-cyclical movement, unfortunately, empirical evidence is very limited. The main difficulty has been the lack of available LTV ratio data. Goodhart *et al.* (2008) look for such pro-cyclical evolution in a cross country methodology [4]. Outcome of his empirical work is not in favour on the intuition of this paper. In spite of this result, Goodhart *et al.* (2008) states:

"The experiences of the more recent episode make a clearer case for the view that LTV 's are pro-cyclical. In the UK, for example, LTV 's had been consistently easing prior to mid 2007, with many mortgages having a LTV of 100 % and even some of 125 %. Recently, LTV 's have gone down below 100%, and some fist-time borrowers are being required to meet LTV 's of 75% if they want to get the best rates" .

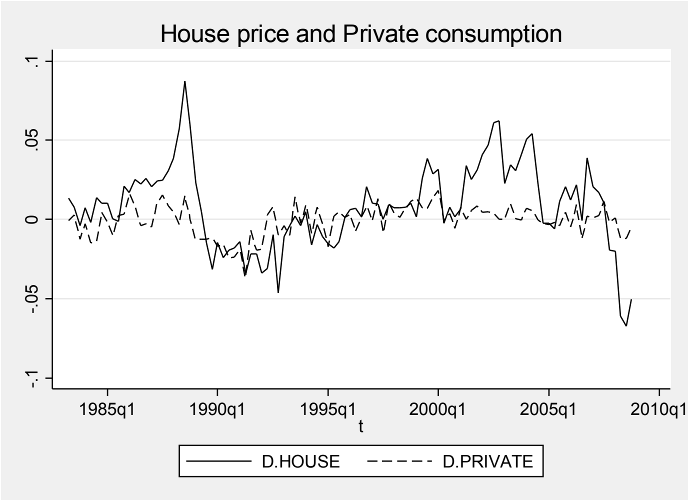
UK Mortgage deregulation

Flexible mortgage market in UK economy is the consequence of removed regulatory measures in the period 1980-1986. The aim of this financial deregulation was to improve competition in the mortgage market. Banks, who traditionally provided only a small share of the total amount of mortgages, were allowed to compete directly with building societies in the mortgage market. Furthermore, other non-bank entrants like retailers and insurance companies have been able to offer some mortgage products. The increasing competition and the lifting in restrictions allowed to extract equity more easily but also to reduce the down-payment when house price goes up. Thus, the link between housing prices and consumption was increased.

Figure 1 and Figure 2 show the co-movement of real housing price growth to respectively private consumption and real domestic product evolution in UK during and *post* mortgage deregulation.

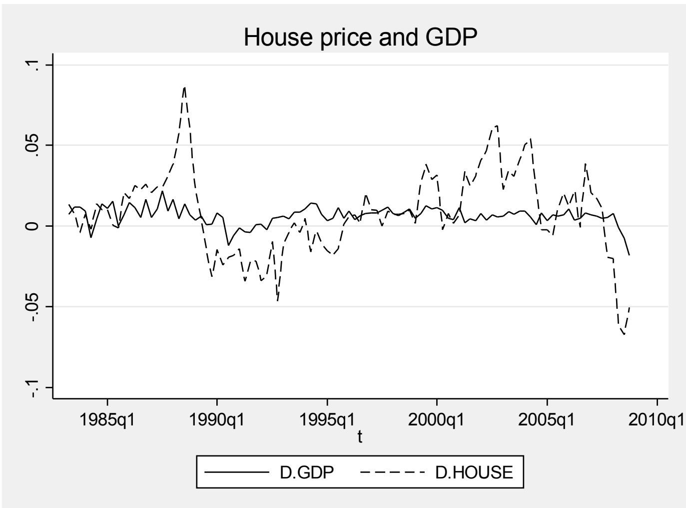
4 The authors identify house price boom periods and collect data of evolution in typical and maximum LTV ratios. Problems in data concerning LTV ratios are underlined.

Figure 1



Note: Both variables are taken in natural logarithm s and are stationarized using the difference operator.

Figure 2



Note. Both variables are taken in natural logarithms and are stationarized using the difference operator.

III. Empirical features in UK output response to housing shocks

In this section I use the vector autocorrelation framework to capture the link between output and real housing price in UK over roughly the last 25 years.

I construct and estimate a vector autocorrelation model (VAR) for the UK economy. The model is set in quarterly data over the sample period 1983:1 – 2008:4. Five endogenous variables are included: real housing prices (deflated with the deflator private consumption index and seasonally adjusted) , the three month mean nominal interest rate, real gross domestic product (deflated with the GDP deflator and seasonally adjusted), real effective exchange rate and the growth in the consumer price index. Instead Iacoviello (2005), I include the real effective exchange rate to capture the open economy influences that, while secondary for the U.S. economy, are likely to matter for a relatively open economy as UK.

All variables are specified in difference and are set in natural logarithms. I added a constant as exogenous variable. One lag-length is optimal to built this model according to AIC and SBIC informational criterion.

I report description of the data sources in Annex A. Table 2 below describe variable labels used in the empirical analysis.

Table 2

Variable labels for empirical analysis

HOUSE	Real housing price
RATE	Short run nominal interest rate
GDP	Real gross domestic product
REER	Real effective exchange rate
PI	Inflation rate
D. or Δ	Difference operator

The constructed vector autocorrelation model is stable, namely, all the eigenvalues in absolute terms lie inside the unit circle, then, the empirical inference is possible. Results of the stability condition for the estimated VAR are presented in Table 3.

Table 3

Eigenvalue stability condition

Eigenvalue	Modulus
.7093038	.709304
.4024963 + .1405771i	.426339
.4024963 - .1405771i	.426339
.2742499	.27425
-.01141	.01141

Note. All the eigenvalues lie inside the unit circle
VAR satisfies stability condition

I proceed to an impulse-responses analysis of the vector autocorrelation model constructed. In this aim, a standard Cholesky methodology to orthogonalize shocks are used follow Sims (1980). Consequently, I proceed to Granger causality tests between the endogenous variables to determine the order of shocks orthogonalization. Consequently, the more exogenous variable will be placed at the top of the VAR [5] .The Granger causality test issues are collected in Table 4.

5 The approach of Granger causality is not a true causality test. More precisely, it is a measure of the forecasting ability of the actual and past values of a given variable, to predict another variable evolution.

Table 4

Granger causality Wald tests

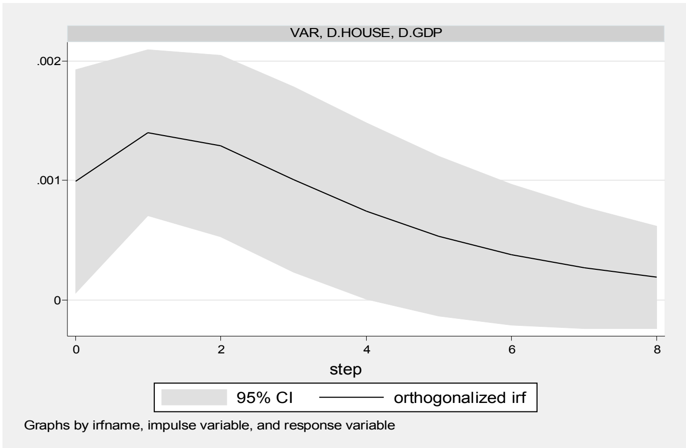
Equation	Excluded	χ^2	df	Prob > χ^2
D_HOUSE	D.RATE	1.7954	1	0.180
D_HOUSE	D.GDP	.68467	1	0.408
D_HOUSE	D.REER	.15978	1	0.689
D_HOUSE	D.PI	2.5399	1	0.111
D_HOUSE	ALL	8.0848	4	0.089
D_RATE	D.HOUSE	8.4911	1	0.004
D_RATE	D.GDP	.88086	1	0.348
D_RATE	D.REER	1.0728	1	0.300
D_RATE	D.PI	.22957	1	0.632
D_RATE	ALL	17.642	4	0.001
D_GDP	D.HOUSE	10.769	1	0.001
D_GDP	D.RATE	.02853	1	0.866
D_GDP	D.REER	.19741	1	0.657
D_GDP	D.PI	.75714	1	0.384
D_GDP	ALL	11.989	4	0.017
D_REER	D.HOUSE	.05982	1	0.807
D_REER	D.RATE	8.4261	1	0.004
D_REER	D.GDP	6.1203	1	0.013
D_REER	D.PI	2.1795	1	0.140
D_REER	ALL	18.156	4	0.001
D_PI	D.HOUSE	4.6164	1	0.032
D_PI	D.RATE	9.0505	1	0.003
D_PI	D.GDP	.37182	1	0.542
D_PI	D.REER	3.4276	1	0.064
D_PI	ALL	29.056	4	0.000

Note. The null hypothesis is non causality.

According to the above results, the housing price variable is the more exogenous variable in the model, namely, the house price variable seems not to be Granger-caused by other variable. Otherwise, the more endogenous variable is unambiguously the inflation rate growth. I retain for the Cholesky-decomposition the following order: real housing price, real gross domestic output, short time interest rate, real effective exchange rate and inflation rate.

I proceed to an impulse-response analysis of the estimated VAR. Figure 3 shows a response of GDP growth to a one standard deviation (about 1.5%, confer Annexe A) house price growth shock [6].

Figure 3



Note. Response of GDP variable to a one standard deviation housing price growth shock.

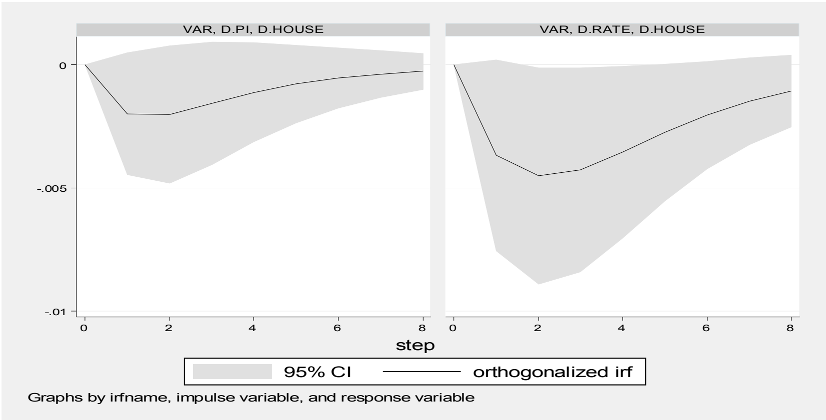
The VAR impulse-response suggests that a shock of 1.5% in the house price growth raises the GDP growth, with a peak response of roughly 0.14% one period following the shock.

In one hand, Figure 4 presents the response of housing price growth to an inflation rate evolution and interest rate variation shock. In another hand, Figure 5 shows the evolution of GDP growth confronted with the same mentioned shocks. Together, Figure 3 to 5, suggest that the housing prices probably have had a pro-cyclical role in the last years in the UK business cycle [7].

6 Henceforth, for all impulse-responses graphs the confidential intervals are estimated by a standard bootstrapped methodology.

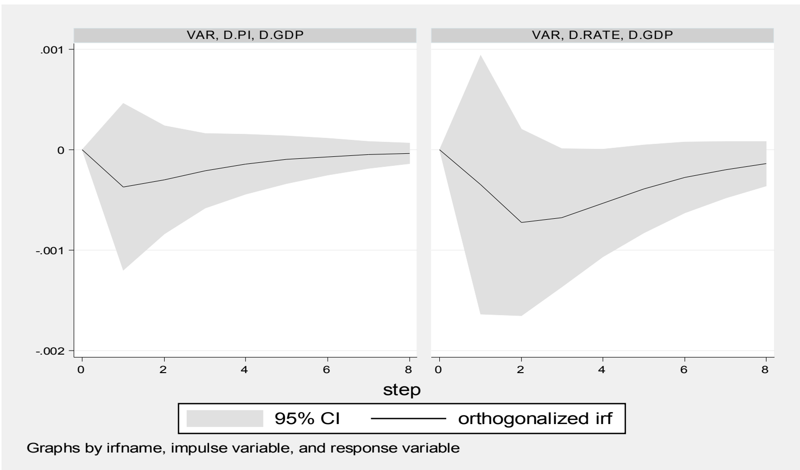
7 In Annexe A, I construct and estimate a VAR model where I replace the private consumption to GDP. I find that for the same shock in housing price variable, the private consumption growth increases above 0.4%, which is considerably more important than the peak response of GDP growth (0.14).

Figure 4



Note. Response of housing variable to a one standard deviation inflation rate and interest rate shock.

Figure 5



Note. Response of GDP growth to a one standard deviation inflation rate and interest rate shock.

Later on, I proceed to estimate an structural vector autocorrelation model (SVAR). Unlike standard VAR methodology, SVAR models introduce structural restrictions (namely, non-sample information) to orthogonalize innovations. Economy theory is used to identify short and long run restrictions. In this work I focus on the contemporaneous necessary restrictions in the model to identify the shocks.

The SVAR model is explicitly represented by equations (V.1) to (V.5) :

(V.1) $\Delta PI_t = a\,\Delta GDP_t + b\,\Delta RATE + c\,\Delta HOUSE_t + d\,\Delta REER_t + lagged\ variables$

(V.2) $\Delta GDP_t = e\,\Delta PI_t + f\,\Delta RATE_t + g\,\Delta HOUSE_t + h\,\Delta REER_t + lagged\ variables$

(V.3) $\Delta RATE_t = i\,\Delta PI_t + j\,\Delta GDP_t + k\,\Delta HOUSE_t + l\,\Delta REER_t + lagged\ variables$

(V.4) $\Delta HOUSE_t = m\,\Delta PI_t + n\,\Delta GDP_t + p\,\Delta RATE_t + q\,\Delta REER_t + lagged\ variables$

(V.5) $\Delta REER_t = r\,\Delta GDP_t + s\,\Delta RATE_t + t\,\Delta HOUSE_t + u\,\Delta PI_t + lagged\ variables$

Note. The complete SVAR model include 1 lag on the endogenous variables and a constant.

As is well known in time series literature, the number of restrictions which are necessary to identify the model shocks depends in the number of endogenous variables. More precise, restriction number equals $N(N-1)/2$, where N is the number of endogenous variables. Thus, in this model, I impose ten contemporaneous restrictions:

$$a=b=c=d=f=g=h=k=l=p=0$$

The imposed restrictions in the estimation of the SVAR implies that the inflation rate evolution and GDP growth respond to variations in the interest rate growth only with a lag [7]. Otherwise, policy can responds to changes in these variables contemporaneously (within a quarter) [8]. Moreover, the so-called "informational" variables, housing price inflation and real exchanges rate evolution, appear at the end of the SVAR, namely, both variables respond contemporaneously to all shocks (the only exception is the variable housing prices who responds to a shock in the exchange rates with a lag) [9].

7 Sousa (2006) imposes the same restriction in model shocks identification.

8 I keep this assumption in the general equilibrium model later described.

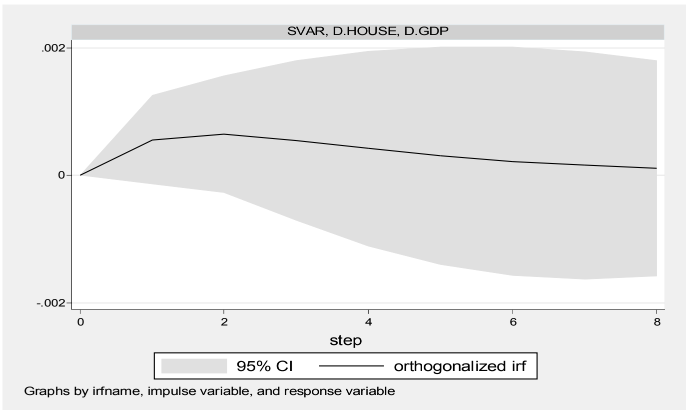
9 As mentioned, the exchange rate evolution is assumed to respond to all variables, this is a common assumption in SVAR studies, see for instance, Berkelmans (2005) .

Figure 6 shows a response of GDP evolution to a one standard deviation housing price growth shock [10].

The SVAR shows that a shock of 1.5% in the house price growth bring an increase in the GDP evolution, with a peak response inferior to 0.1% , which is less than the response of output variable in the VAR model. Furthermore, one can remark that after only 2 quarters the concerned impulse-responses are inconclusive due to large confidential intervals range. Regarding the responses of output growth and housing price variation to a shock on inflation rate and on interest rate growth, results are less in favour of a co-movement between the two variables than for the VAR approach. Furthermore, it is relevant to notice the non-intuitive positive response of real housing price growth to an interest rate tightening showed in Figure 8.

Overall, results show that a different order of orthogonalization of shocks can produce a different impulse-responses in this model. Nevertheless, both VAR and SVAR model bring a non ambiguous evidence of a link between real house price evolution and output growth in the short run.

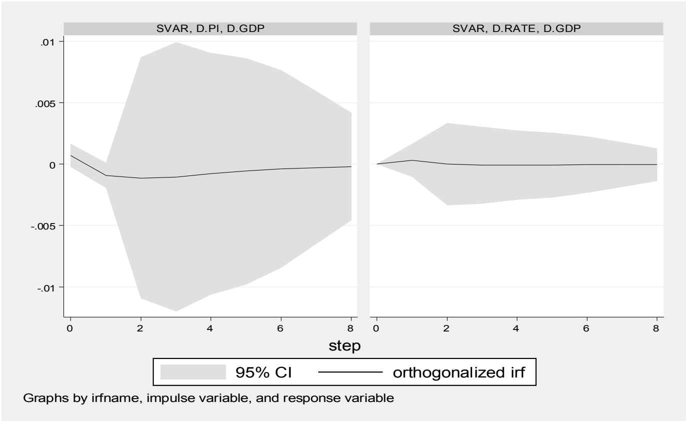
Figure 6



Note. Response of GDP variable to a one standard deviation housing price growth shock.

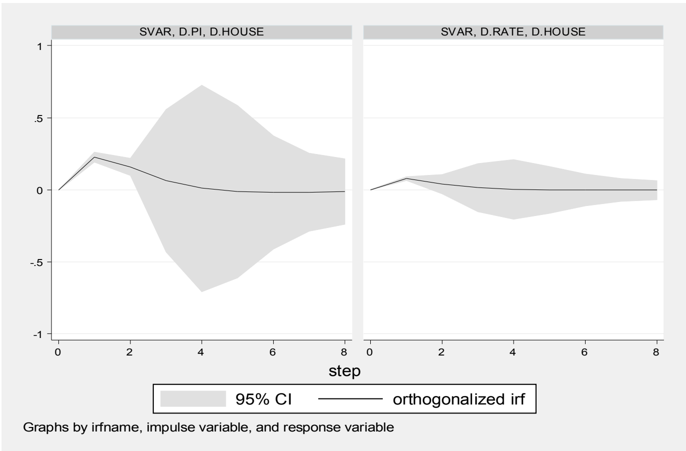
10 Of course, as I keep the same sample for the estimation, the value of the standard deviation housing price shock is the same than for the VAR model.

Figure 7



Note. Response of GDP growth to a one standard deviation inflation rate and interest rate shock.

Figure 8



Note. Response of housing variable to a one standard deviation inflation rate and interest rate shock.

III. The Model

The framework presented here is a model with frictions in the credit market. Consequently, a share of the population is not allowed to inter-temporaly smoothen his consumption in an optimal way. The other fraction of households have accumulated enough wealth so that their consumption decisions are well approximate by the permanent income hypothesis.

Thus, the considered economy is populated by credit "*unconstrained*" and "*constrained*" infinitely lived households. There are a continuum of these households of measure one. The two types of agents feature heterogeneous preferences, namely, the "unconstrained" households has, by assumption, a lower discount rate than the "constrained" one. Households consume, work and demand real state. Moreover , the economy is constituted by infinitely lived *entrepreneurs* who produce a homogeneous good, hiring household labour and using real state. Otherwise, I call *central bank* the entity who supports an interest rate rule and finally, *retailers* who allow to introduce nominal rigidity in the model.

A. Unconstrained Households

Unconstrained households (denoted with a prime) maximise the following lifetime utility function :

$$E_o \sum_{t=0}^{\infty} \beta^{t} {}' (lnc'_t + j_t lnh'_t - \frac{(L'_t)^{\eta}}{\eta})$$

where E_0 is the expectation operator, β' is the discount factor, c'_t is consumption at date *t,* j_t is a function of the marginal utility of housing, h'_t denotes holdings on real state, L'_t are hours of work and η is roughly the inverse of labour supply elasticity.

The maximisation of the utility function above is subject to the following budget constraint:

$$c'_t + q_t(h'_t - h'_{t-1}) + \frac{R_{t-1} b'_{t-1}}{\pi_t} = b'_t + w'_t L'_t + F_t \qquad (1)$$

where, q_t is the real housing price, R_{t-1} represent the nominal interest rate on loans between t-1 and t , b'_{t-1} is the nominal amount lent (or borrowed) in t-1, π_t is the gross inflation rate ($\pi_t = P_t / P_{t-1}$), w'_t is the real wage, F_t are lump-sum profits received from the retailers (confer infra).

The first order conditions with respect to consumption, housing demand and labour supply are:

$$\frac{1}{c'_t} = E_t\left(\frac{\beta' R_t}{\pi_{t+1} c'_{t+1}}\right) \qquad (2)$$

$$\frac{q_t}{c'_t} = \frac{j_t}{h'_t} + \beta' E_t\left(\frac{q_{t+1}}{c'_{t+1}}\right) \qquad (3)$$

$$\frac{w'_t}{c'_t} = (L'_t)^{\eta-1} \qquad (4)$$

B. Constrained Households

The objective function for the constrained households is represented by :

$$E_o \sum_{t=0}^{\infty} \beta^{t}{}''(lnc_t'' + j_t lnh_t'' - \frac{(L_t'')^{\eta}}{\eta})$$

where, by assumption, $\beta''<\beta'$ and double prime denoting variables associated to the constrained households.

The next equation describes the budget constraint

$$c_t''+q_t(h_t''-h_{t-1}'')+\frac{R_{t-1}b_{t-1}''}{\pi_t}=b_t''+w_t''L_t'' \qquad (5)$$

A central assumption in the borrower-lender framework mechanism are set in Kiyotaki *et al.*1997's paper. In their set-up, agents can borrow until a limit which is proportional to their net worth. In this model, agents can borrow an amount what is proportional to the value expected by lenders in housing holdings. Thus, all the expected housing value could not be used as collateral. One can think, to explain this assumption, to the case when the borrowers repudiate their debt, then, lenders will have to pay a transaction cost to repossess borrowers' assets. This is the raison because not all housing holdings can be collateralized. The later hypothesis is materialized in the next relation:

$$R_t b_t''\leq E_t(m''_t q_{t+1} h_t''\pi_{t+1})$$

where m'' is the LTV ratio and $(1-m'')E_t(q_{t+1}h_t)$ is the proportional transaction cost paid by lenders.

In fact, the assumption $\beta''<\beta'$ guarantees that the borrowing constraint will be saturate in the steady state and in his neighbourhood if there is not uncertainty. (confer Iacoviello 2005's article for further explanations). Consequently, the binding constraint is given by:

$$R_t b_t''=E_t(m''_t q_{t+1} h_t''\pi_{t+1}) \qquad (6)$$

The LTV ratio of the constrained households is assumed to be non constant. Let's assume that the loan-to-value ratio at t is a function of the gap between the expected value on $t+1$ of the real housing price and his stationary value.

$$m''_t-m''=f(q_{t+1}-q)$$

with $f'>0, f''<0$

where m'' and q are the steady state values of the loan-to-value ratio for the constrained households and for the real housing price, respectively.

The loan-to-value ratio can be seen as a measure of the risk taken by lenders. A higher LTV ratio is associated to a higher risk taken in the lending operation. As is well known, in times of boom, agents has a propensity to undervalue risk. This is the story told in the above equation. If lenders expect a higher real housing prices, they will rise the LTV ratio of the collateralized loans. This relation between LTV ratio and housing price expectations is intuitively more likely to be verified in an strong competitive mortgage market environment. It is the case for the UK mortgage market after the deregulation of the 80's.

The assumption of concavity reflect the hypothesis that as the difference between the expected housing price and the housing price at the steady state goes up, lenders will consider their housing price expectations as less and less reliable, namely, more volatile. Consequently, the LTV ratio rises less and less as the gap between real housing prices expectations and housing price at the steady state value increases. Explicitly,

$$m''_t - m'' = \phi E_t (q_{t+1} - q)^{\sigma}$$ [11]

with $\sigma \in [0,1]$ and $\phi \in \Re^{+}$.

Solving the problem gives the first order conditions with respect to respectively consumption, housing demand and labour supply :

$$\frac{1}{c_t''} = E_t \left(\frac{\beta'' R_t}{\pi_{t+1} c''_{t+1}} \right) + \lambda''_t R_t \tag{7}$$

$$\frac{q_t}{c_t''} = \frac{j_t}{h_t''} + E_t \left(\frac{\beta'' q_{t+1}}{c''_{t+1}}'' + \lambda''_t m''_t q_{t+1} \pi_{t+1} \right) \tag{8}$$

$$\frac{w_t''}{c_t''} = (L_t'')^{\eta - 1} \tag{9}$$

11 To take in account the inertia in fixation of LTV ratio, one could transform the above equation simply in: $m''_t - m'' = \rho (m''_t - m'') + \phi E_t (q_{t+1} - q)^{\sigma} \, with \, \rho \in [0,1]$.

where λ'' is the shadow price associated to the borrowing constraint (6). More precise, λ'' equals the increase in inter-temporal utility that the representative constrained household receive when he borrows R_t supplementary units of euros, for instance. The concerned agent uses the loan to rise consumption, and then utility, at time *t*. In *t+1*, the constrained household reduces consumption to be able to repaid his one period maturity loan, thus, his utility is diminished. Nevertheless, the net effect in lifetime utility is positive.

C. Entrepreneurs

Assume that the entrepreneurs are in a competitive market. They maximise the next utility function:

$$E_o \sum_{t=0}^{\infty} \gamma^t \ln c_t$$

where $\gamma < \beta'$, subject to the budget constraint, the technology constraint and the borrowing constraint.

The technology of production used by entrepreneurs to produce the intermediate good Y_t is a Cobb Douglas function with constant returns to scale :

$$Y_t = A_t K_{t-1}^{\mu} h_{t-1}^{\nu} L'^{\alpha(1-\mu-\nu)}_t L''^{(1-\alpha)(1-\mu-\nu)}_t \qquad (10)$$

where A is a technology parameter. Intermediate good cannot be transformed directly into consumption (c_t) .

Entrepreneurs budget constraint is defined by :

$$\frac{Y_t}{X_t} b_t = c_t + q_t (h_t - h_{t-1}) + \frac{R_{t-1}}{\pi_t} b_{t-1} + w'_t L'_t + w''_t L'_t + I_t + \xi_{K,t} \qquad (11)$$

where I_t equation has the standard form : $I_t = K_t - (1-\delta) K_{t-1}$. Supplementary purchase of capital entails the following unitary cost: $\xi_{K,t} = (\psi/2\delta)(I_t/K_{t-1} - \delta)^2 K_{t-1}$.

In the same way that the constrained households, entrepreneurs borrowing capacity is limited by the below equation:

$$R_t b_t \leq m\, q_{t+1} h_t \pi_{t+1}$$

The borrowing constraint is bounded in and around the steady state (*confer supra*).

$$R_t b_t = m_t q_{t+1} h_t \pi_{t+1} \tag{12}$$

In lieu of constrained households, I assume that the LTV ratio for entrepreneurs is constant. The first order conditions respect to respectively nominal amount borrowed, investment, capital holding , real state holding, demand for unconstrained households labour and demand for constrained households labour are:

$$\frac{1}{c_t} = E_t\left(\frac{\gamma R_t}{\pi_{t+1} c_{t+1}}\right) + \lambda_t R_t \tag{13}$$

As for the constrained household, the standard Euler equation for entrepreneurs is modified by a function of the shadow price associated to the borrowing constraint equation.

$$u_t = \frac{1}{c_t}\left[1 + \frac{\psi}{\delta}\left(\frac{I_t}{K_{t-1}} - \delta\right)\right] \tag{14}$$

$$u_t = E_t\left[\frac{\gamma}{c_{t+1}}\left[\frac{\psi}{\delta}\left(\frac{I_{t+1}}{K_t} - \delta\right)\frac{I_{t+1}}{K_t} - \frac{\psi}{2}\delta\left(\frac{I_{t+1}}{K_t} - \delta\right)^2\right]\right]$$

$$+ \gamma E_t\left[\mu \frac{Y_{t+1}}{c_{t+1} X_{t+1} K_t} + u_{t+1}(1-\delta)\right] \tag{15}$$

where u is the shadow price associated to investment ("Tobin's u").

$$\frac{q_t}{c_t}=E_t[\frac{\gamma}{c_{t+1}}(\nu\frac{Y_{t+1}}{X_{t+1}h_t}+q_{t+1})+\lambda_t m_t \pi_{t+1} q_{t+1}] \quad (16)$$

$$w'_t=\frac{\alpha(1-\mu-\nu)Y_t}{X_t L'_t} \quad (17)$$

$$w''_t=\frac{(1-\alpha)(1-\mu-\nu)Y_t}{X_t L_t''} \quad (18)$$

D. Retailers

Following Bernanke *et al.* (1999), to introduce price inertia in this framework, the assumption of monopolistic competition at the retail level and an implicit cost of adjusting nominal prices is used.

An infinity of retailers are distributed in a continuum of mass 1. Each retailer is indexed by z. They buy intermediate goods from the entrepreneurs and sell a no cost differentiated product.

As in Bernanke *et al.* (1999), I assume that retailers purchase the intermediate output at the price P_t^w and transform it into a final good, which will be sold to households and to

entrepreneurs at the price P_t. Thus, the unitary mark-up of final over intermediate goods is denoted X_t. Each retailer sell the amount $Y_t(z)$ of final good at the price $P_t(z)$.

The aggregation of individual retail goods has the following expression :

$$Y_t=(\int_0^1 Y_t(z)^{(\varepsilon-1)/\varepsilon} dz)^{\frac{\varepsilon}{(\varepsilon-1)}}$$

with $\epsilon>1$. The corresponding price index is given by:

$$P_t = \left(\int_0^1 P_t(z)^{(1-\varepsilon)} dz\right)^{\frac{1}{(1-\varepsilon)}}$$

With the two last equations one can obtain the individual demand addressed to each retailer: $Y_t(z) = (P_t(z)/P_t)^{-\varepsilon} Y_t$. The retailer then chooses the sale price $P_t(z)$ taking as given the price of wholesale goods (P_t^w) and the demand curve.

Furthermore, following Calvo (1983), I suppose that the retailer is free to change its price in a given period only with probability $1-\theta$. The price set by retailers who are able to change their price at *t* is denoted $P_t^s(z)$. Moreover, let's set $Y_t^s(z)$ the demand given the price $P_t^s(z)$. Each retailer fixes his price to maximise expected discounted profits given by the below equation:

$$\sum_{k=0}^{\infty} \theta^k E_t \{\Lambda_{t,k} \frac{P_t^s(z) - P_t^w}{P_t} Y_{t+k}^s(z)\}$$

where $\Lambda_{t,k} = \beta'(c'_t / c'_{t+k})$ is the unconstrained household (the shareholder) inter-temporal marginal rate of substitution. Differentiating the objective function with respect to P_t^s implies that the optimally price solves:

$$\sum_{k=0}^{\infty} \theta^k E_t \{\Lambda_{t,k} (\frac{P_t^s(z)}{P_{t+k}} - \frac{X}{X_{t+k}}) Y_{t+k}^s(z)\} = 0 \qquad (19)$$

where X is the steady state value of the mark-up and equals $X = \epsilon/(\epsilon - 1)$.

Otherwise, the aggregate price level evolution is:

$$P_t = [\theta P_{t-1}^{\varepsilon} + (1-\theta)(P_t^s)^{(1-\varepsilon)}]^{\frac{1}{(1-\varepsilon)}} \qquad (20)$$

By combining equation (19) and (20) and then log-linearising, it is possible to get a forward-looking New Phillips curve:

$$\hat{\pi}_t = \beta' E_t \hat{\pi}_{t+1} - \kappa \hat{X}_t$$

with $\kappa=(1-\theta)(1-\beta'\theta)/\theta$. Where $\hat{\pi}_t$ and $\hat{X}_t$ are the gross inflation rate and mark-up log-linearised around the steady state.

Finally, retailers profits are transferred to the unconstrained households.

E. Central Bank Behaviour

The central bank is able to control the nominal rate and uses this instrument to follow a Taylor-type interest rate rule of the form:

$$R_t=(R_{t-1})^{r_R}[(\pi_t/\pi)^{1+r_\pi}(Y_t/Y)^{r_y}(R/\pi)]^{1-r_R}e_{R,t} \quad (21)$$

where π, Y, R are the steady state values to respectively the gross inflation rate, the output and the nominal rate. A white noise process $(e_{R,t})$ with zero mean and variance σ_e^2 is put in the equation to represent the unexpected shocks on interest rate variable.

F. Markets and equilibrium

The market clearing conditions for housing holdings, goods and loans are given respectively by:

$$1=h_t+h'_t+h_t''$$ [12]

(22)

$$Y_t=c_t+c'_t+c_t''+I_t \quad (23)$$

$$-b'_t=b_t+b_t'' \quad (24)$$

12 Total amount of housing holdings are fixed and normalized to 1.

The model has a unique stationary equilibrium in which entrepreneurs and constrained households hit their borrowing constraint (and then borrow up to the limit). The equilibrium is an allocation $h_t, h'_t, h''_t, L'_t, L''_t, Y_t, c_t, c'_t, c''_t, b_t, b'_t, b''_t$ together with the sequence of values $w'_t, w''_t, R_t, P_t, P^s_t, X_t, \lambda_t, \lambda''_t, q_t$ satisfying equations (2) to (21) and the market clearing conditions: equations (22) to (24), with the concerned no-Ponzi game conditions.

IV. Dynamics around the neighbourhood of the steady state

The aim of this section is to simulate the dynamics of the model in the proximity of a zero inflation steady state. The UK economic conditions before the sub-prime crises are taken to calibrate the model. Log-linearisation is used to obtain an analytical solution and then to simulate the dynamics of the model.

The equations describing a zero inflation steady state $(\pi=1)$ as well as the log-linearised equations can be found in Annexe B.

A. Calibration

The benchmark parametrization of the model is described in this sub-section. All the parameters are set to match a quarterly frequency.

The discount factors are picked directly from Iacoviello's 2005 paper. Thus, the discount factor for the unconstrained households (β'), constrained households (β'') and entrepreneurs (γ) are 0.99, 0.95 and 0,98, respectively. The parameters X, δ, η and μ are set in line with their standard values in the business cycle literature, then, the values chosen are respectively 1.05, 0.03, 1.01 and 0.3 .

Follow Hall (2001) , I set the probability of change prices of differentiated goods, $(1-\theta)$, 0.5. Moreover, the steady state value of LTV ratio for constrained UK households, (m'') , are fixed at 0.70, following Aoki et al (2002) [13]. The loan-to-value ratio for entrepreneurs is fixed at 0.70 also. The parameter σ and ϕ are set to 1 and 0.31 in the baseline simulation [14] .

13 Likewise, Calza *et al.* (2006) estimate the average value of LTV' ratio for new loans at 0.7 for UK.

14 The value $\phi=0.31$ fix the LTV ratio growth within a quarter to about 3.6% when the economy at the steady state is hit by a 1% increase in real housing price, this implies that the LTV ratio will be 0.725 at the end of the period. In simulations not reported here, even though when the increase in LTV ratio is set to only 1.4%, one obtain a meaningful effect on output variation.

The parameter of housing preference , j , is set to 0.2. This number implies a plausible 150 percent for the steady state value of the stock of housing over output in the UK economy.

Regarding the interest rate rule equation, the parameters r_R, r_π, r_Y are set to respectively 0.9, 1 and 0 as Aoki *et al.* 2002 's framework. For the white noise process $e_{R,t}$, I set a standard error of 0.66 [15].

In Disney et al. (2006), the authors empirical results show that the typical proportions of collateral constrained households, assumed in most of the models based on calibration, is probably too high to fit recent UK features. Accordingly, I choose a low value with respect to the literature used values. A proportion of constrained households of 21 percent, which corresponds in the model to $\alpha = 0.79$, is picked to the Iacoviello and Neri 2008's article.

I consider in the simulations three shocks which follow an autoregressive process of order 1. A technological shock, an inflation shock and a housing preference shock. The standard error values are set respectively 0,28 (σ_A) ,0.17 (σ_u) and 24.89 (σ_j) . Concerning the autocorrelation parameters, they are respectively set 0.90 (ρ_A) ,0.59 (ρ_u) and 0.85 (ρ_j) . All these parameters are picked to Iacoviello (2005) excluding the autocorrelation parameter of the productivity shock, which is taken from Aoki *et al.* (2002) and the standard error of the productivity shock, taken from Hall (2001) [16] . Eventually, I set ν equal to 0,03 and ψ equal to 2, again, in line with my benchmark paper.

Table 4 and 5 summarizes the parameters for the baseline simulation.

15 On the first glance, the standard error value for the white noise process could be appear as too high. Nevertheless, last evolutions in interest rates in UK justify extensively this picked value.

16 The value 0.03 estimated and set by Iacoviello (2005) is very far to the consensus in the business cycles literature.

Table 4

Calibrated and estimated parameters in the baseline model

Description	Parameter	Value
Discount factors		
Unconstrained households	β'	0.99
Constrained households	β''	0.95
Entrepreneurs	γ	0.98
Factors shares		
Unconstrained households share	α	0.79
Variable capital share	μ	0.3
Housing share	ν	0.03
Loan to value parameters		
Loan to value ratio entrepreneurs	m	0,89
Loan to value ratio unconstrained	m''	0,70
Concavity parameter in the LTV function	σ	1
Scale parameter in the LTV function	ϕ	0.31
Preference parameters		
Labour supply aversion	η	1.01
Weigh on housing service	j	0.1
Sticky prices		
Steady state mark-up	X	1.05
Probability to fix price	θ	0.5
Capital technology parameters		
Capital adjustment cost	ψ	2
Capital depreciation rate	δ	0.03

Table 5

Standard Errors and autocorrelations values in the baseline model

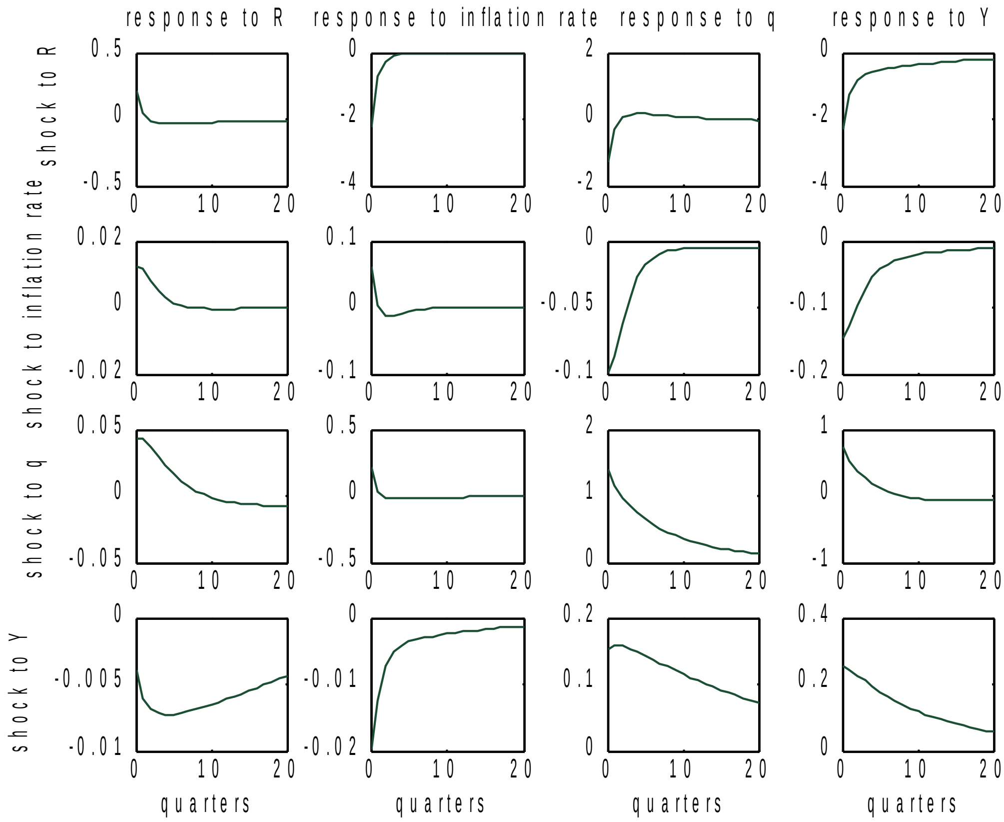
Description	Parameter	Value
Standard deviations of shocks		
Inflation	σ_u	0.17
Interest rate	σ_e	0.66
Housing preference	σ_j	24.89
Technology	σ_A	0.28
Autocorrelation of shocks		
Inflation	ρ_u	0.59
Housing preference	ρ_j	0.85
Technology	ρ_A	0.90

Figure 1 shows the model impulse responses with the baseline calibration. A monetary tightening can be observed in the first row. Real output, inflation rate and real housing prices decrease [17] , which is consistent with the standard economic intuitions. Concerning inflation rate shock (row 2), interest rate rises and real housing price goes down as expected. Third row of figure 1 shows a preference housing shock (which implies an increase in real housing price variable in the model). In line with financial accelerator literature, I find a strong response of aggregate demand to a housing shock [18]. Furthermore, the model simulation shows a positive elasticity of inflation rate to a housing price shock. Finally, the last row reports responses to a transitory productivity shock (which implies an increase in aggregate production).

17 One can see that the Central Bank implicitly responds to real housing price rising interest rate policy instrument.

18 In a simulation of a shock in real housing price, Iacoviello (2005) obtain even a negative response of aggregate consumption in his "basic model" without financial accelerator mechanism for US economy.

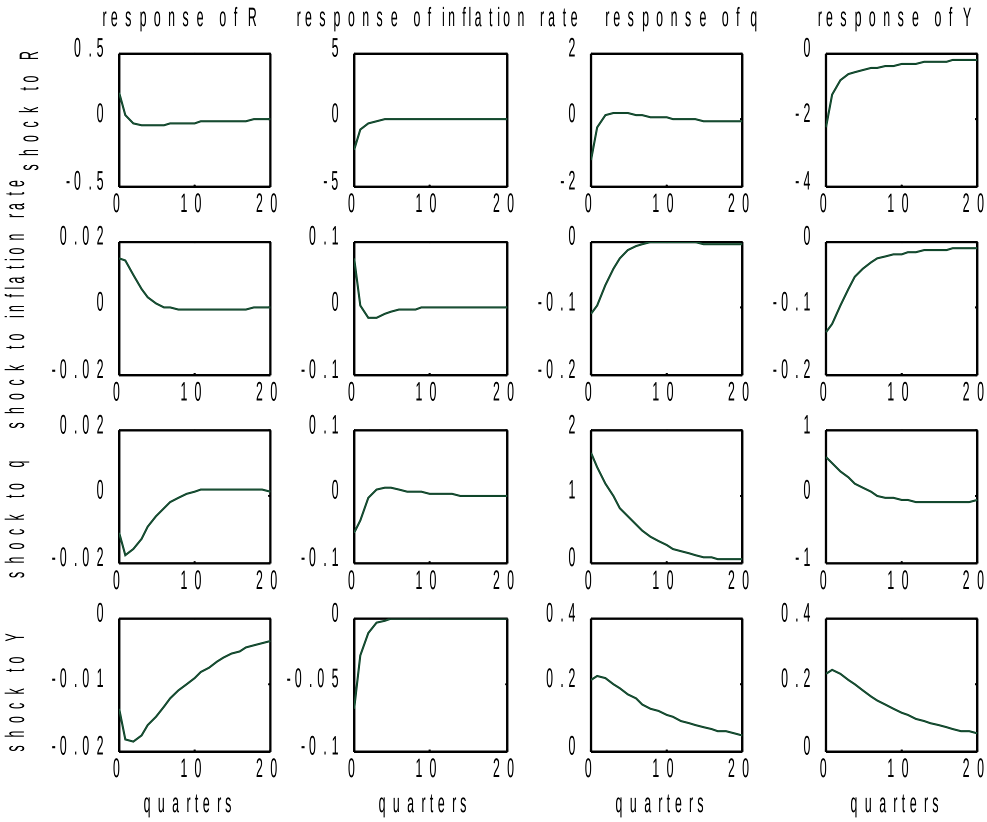
Figure 9. Impulse-responses to all shocks in the baseline calibration



Note: Coordinate, percent deviation from zero inflation steady state

In the aim to quantify the consequences to introduce in the model a time-variant LTV ratio, I simulate, *ceteris paribus,* a model with a constant loan-to-value ratio. Figure 2 reports the impulse responses in the mentioned alternative calibration.

Figure 10. Impulse-responses to all shocks in the alternative calibration



Note: Coordinate, percent deviation from zero inflation steady state

Overall, Figure 1 and 2 show a similar qualitative and quantitative results concerning the responses of variables to an interest rate and inflation rate shock. Regarding the shock to real housing price, the simulation of the alternative calibration model shows a non-intuitive response of inflation rate. More important, one can observe a quantitative difference in the responses of output to a housing price shock. In the baseline model, a rise of about 1.3 percent above the steady state value of the housing price increase output of roughly 0.8 percent. While with the alternative calibration, more than 1.5 percent increase of housing price variable rises slightly more than 0.5 percent real output. This observation implies that a time-variant LTV ratio (as specify in Section IV) is a powerful amplification mechanism in the UK business cycle.

IV. Conclusion

In this paper I have extended Iacoviello 2005's framework to quantify the effects of a pro-cyclical loan-to-value ratio on the business cycle fluctuations. I find that for the UK economy, the mentioned effects can be considerable, in particular on output evolution.

Recently, one can find in the literature discussions about if central bankers whether or nor must respond to housing price deviation from his steady state values. Several implementation problems are underlined on this policy. The determination of steady state housing price value by the monetary authorities is a non negligible problem. Moreover, a tightening policy to respond to a suspected bubble on the housing market shall be hard to communicate in periods of low inflation. Last but not least, this kind of policy set evident problems within a currency union as the European Community, where housing market evolutions are heterogeneous.

In this paper I focused in another issue to attenuate the detrimental effects of a correction in the housing price market, namely, regulation on the LTV ratio. A fixation of an upper bound for LTV ratio, which must be regularly adjusted, or a capital requirement linked to the level of the LTV ratio seem to be judicious policies.

I expect further stress on collecting data in the aim to proceed to supplementary empirical issues on LTV ratio procyclicality.

Annex A

Alternative VAR

An alternative vector autocorrelation model (VAR2) is constructed and estimated for the UK economy. The model is set in quarterly data over the sample period 1983:1 - 2008:4. Five endogenous variables are included: real housing prices (deflated with the deflator private consumption index and seasonally adjusted) , the three month mean nominal interest rate, the real private consumption (deflated with the deflator private consumption index and seasonally adjusted), real effective exchange rate and the consumer price index en change.

All variables are specified in difference and are set in natural logarithms. A constant is added as exogenous variable. One lag is optimal to built this model according to AIC and SBIC criterion.

Stability conditions and Granger-causality tests are reported below.

Eigenvalue stability condition

Eigenvalue	Modulus
.6999529	.699953
.4837751	.483775
.2914885 + .09692064i	.307179
.2914885 - .09692064i	.307179
-.02104309	.021043

All the eigenvalues lie inside the unit circle
VAR satisfies stability condition

Granger causality Wald tests

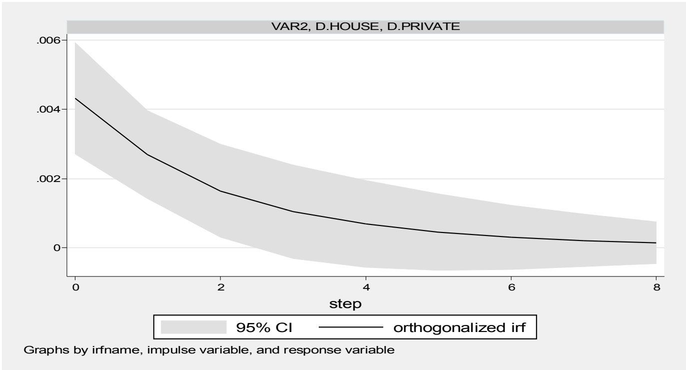
Equation	Excluded	χ^2	df	Prob > χ^2
D_HOUSE	D.RATE	1.8612	1	0.172
D_HOUSE	D.PRIVATE	.34707	1	0.556
D_HOUSE	D.REER	.04038	1	0.841
D_HOUSE	D.PI	2.303	1	0.129
D_HOUSE	ALL	7.7229	4	0.102
D_RATE	D.HOUSE	14.927	1	0.000
D_RATE	D.PRIVATE	2.1134	1	0.146
D_RATE	D.REER	.54097	1	0.462
D_RATE	D.PI	.14513	1	0.703
D_RATE	ALL	19.076	4	0.001
D_PRIVATE	D.HOUSE	2.9414	1	0.086
D_PRIVATE	D.RATE	.3341	1	0.563
D_PRIVATE	D.REER	.21901	1	0.640
D_PRIVATE	D.PI	.43309	1	0.510
D_PRIVATE	ALL	4.3021	4	0.367
D_REER	D.HOUSE	.54965	1	0.458
D_REER	D.RATE	8.3962	1	0.004
D_REER	D.PRIVATE	.00157	1	0.968
D_REER	D.PI	1.5269	1	0.217
D_REER	ALL	11.356	4	0.023
D_PI	D.HOUSE	7.4507	1	0.006
D_PI	D.RATE	8.4926	1	0.004
D_PI	D.PRIVATE	.86816	1	0.351
D_PI	D.REER	2.7818	1	0.095
D_PI	ALL	29.691	4	0.000

Note. The null hypothesis is non causality.

Follow a standard Cholesky-decomposition methodology, I set the following order for the alternative VAR: real housing price, real private consumption, short time interest rate, real effective exchange rate and inflation rate.

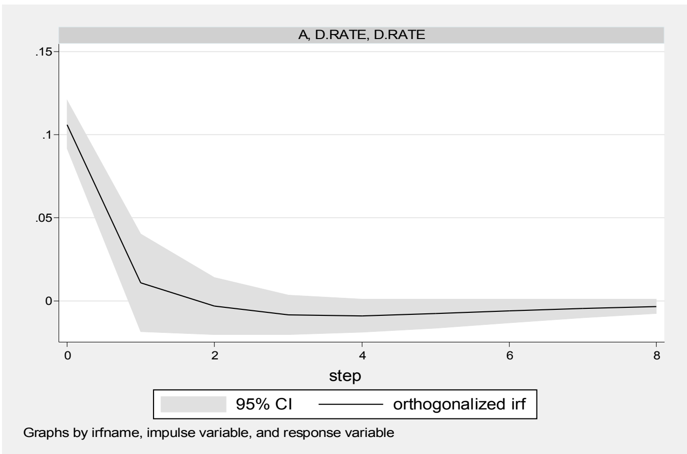
One can see in the next figure a response of private consumption growth to a standard error shock of housing price evolution (roughly 1.5%) . The private consumption variable increases above 0.4%.

House price growth shock and response of private consumption

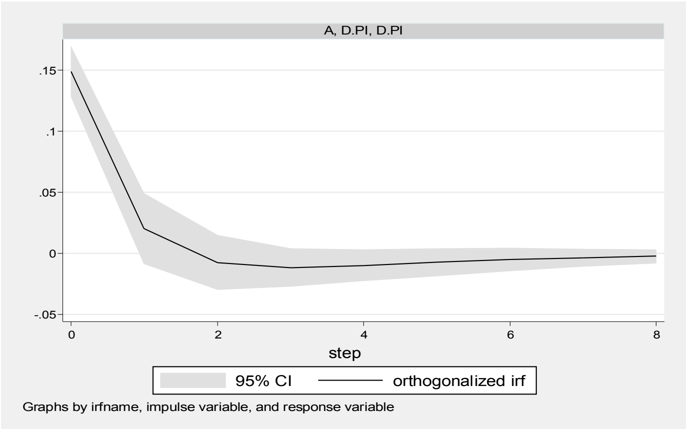


Other shocks and responses in VAR and SVAR models

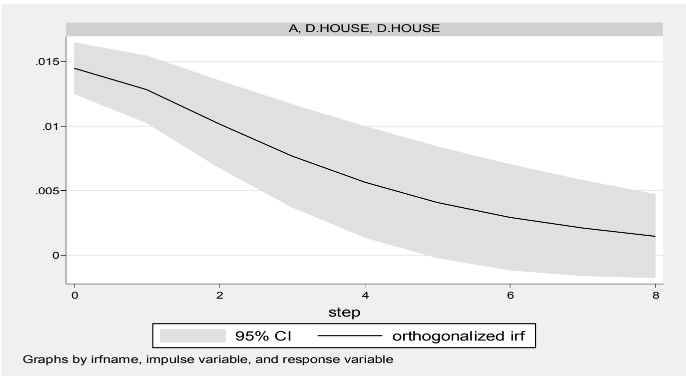
Interest rate growth standard error shock and response in the VAR model



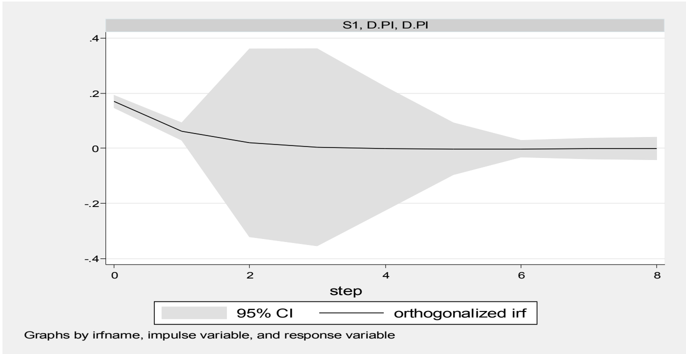
Inflation rate growth standard error shock and response in the VAR model



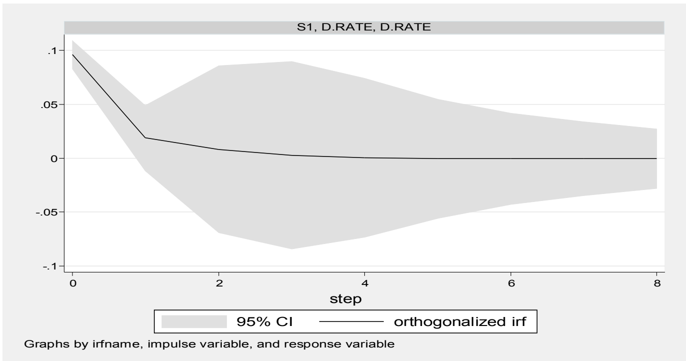
Housing price growth standard error shock and response in the VAR model



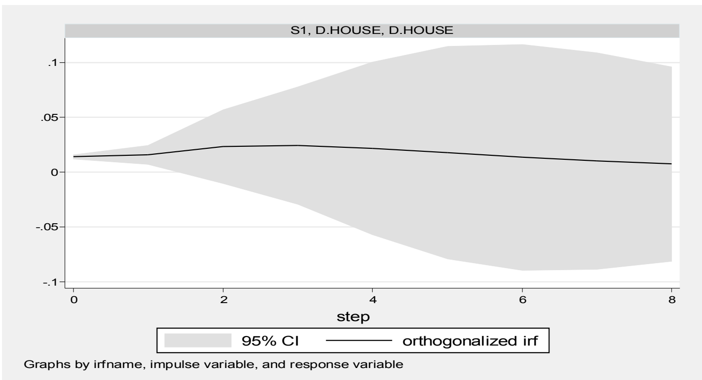
Inflation rate growth standard error shock and response in the SVAR model



Interest rate growth standard error shock and response in the SVAR model



Housing price growth standard error shock and response in the SVAR model



Data source description

Series	Ecowin–Code	Source
Real effective exchange rate	ifs:s11200reczfq	IMF – IFS
Gross domestic product	ifs:s11299b0czfq	IMF – IFS
Nominal short term interest rate	oecd:gbr_ir3tib01_stq	OCDE – MEI
Consumer price index en change(%)	ifs:s1126400xzfq	IMF – IFS
Housing price	ew:gbr03582	Ecowin Eco.
Deflator private final consumption	oe:gbr_pcpq	OECD – EO
Deflator GDP	oecd:gbr_expgdp_dnbsaq	OCDE – MEI

Annex B

Steady state variables

$$\pi = 1 \qquad \text{(SS. 1)}$$

$$R = 1/\beta' \qquad \text{(SS. 2)}$$

$$\delta K = I \qquad \text{(SS. 3)}$$

$$Y = c + c' + c'' + I \qquad \text{(SS. 4)}$$

$$\gamma = (\beta' - \gamma)/c \qquad \text{(SS. 5)}$$

$$\lambda'' = (\beta' - \beta'')/c'' \qquad \text{(SS. 6)}$$

$$F = [(X-1)/X]Y \qquad \text{(SS. 6)}$$

$$K = \frac{\gamma\mu}{[1-\gamma(1-\delta)]X}Y \qquad \text{(SS.7)}$$

$$q = \frac{\gamma\nu}{1-\gamma-(\beta-\gamma)m}\frac{1}{X}Y \qquad \text{(SS. 8)}$$

$$q = \frac{jc'}{h'(1-\beta')} \qquad \text{(SS. 8)}$$

$$q = \frac{jc''}{h''[1-\beta''-m''(\beta'-\beta'')]} \qquad \text{(SS. 9)}$$

$$b = \beta' mqh \qquad \text{(SS. 10)}$$

$$b'' = \beta' m'' qh'' \qquad \text{(SS. 11)}$$

$$c''=w''L''+m''qh''(\beta'-1)$$ (SS. 12)

$$w''L''=(1-\alpha)(1-\nu-\mu)Y/X$$ (SS. 13)

$$w'L'=\alpha(1-\nu-\mu)Y/X$$ (SS. 13)

Equation SS. 13 can be rewritten dividing all the equation by L' and adding on the left and right side FX:

$$w'L'+F=[\alpha(1-\mu-\nu)+X-1]Y/X$$ (SS. 13')

$$c=\frac{\mu+\nu}{X}Y-\delta K-(1-\beta')mqh$$ (SS. 14)

$$Y=AK^{\mu}h^{\nu}L'^{\alpha(1-\nu-\mu)}L''^{(1-\alpha)(1-\nu-\mu)}$$ (SS. 15)

$$w'=L'^{(\eta-1)}c'$$ (SS. 16)

$$w''=L''^{(\eta-1)}c''$$ (SS. 17)

$$b+b''=-b'$$ (SS. 18)

$$1=h_t+h'_t+h''_t$$ (SS. 19)

$$c'=w'L'+F-(\beta'-1)(mqh+m''qh'')$$ (SS. 20)

$$\frac{Y}{X}+b=c+\frac{Rb}{\pi}+w'L'+w''L''+I$$ (SS. 21)

Log-linearised model

1. Aggregated demand

$$\hat{Y}_{t+1}=\frac{c}{Y}\hat{c}_{t+1}+\frac{c'}{Y}\hat{c}'_{t+1}+\frac{c''}{Y}\hat{c}''_{t+1}+\frac{I}{Y}\hat{I}_{t+1} \quad \text{(LL.1)}$$

$$\hat{c}'_{t}=\hat{c}'_{t+1}+\hat{\pi}_{t+1}-\hat{R}_{t} \quad \text{(LL.2)}$$

$$\beta'\hat{c}''_{t}=\beta''\hat{\pi}_{t+1}+\beta''\hat{c}''_{t+1}-\beta'\hat{R}_{t}-(\beta'-\beta'')\hat{\lambda}''_{t} \quad \text{(LL.3)}$$

$$\beta'\hat{c}_{t}=\gamma\hat{c}_{t+1}-(\beta'-\gamma)\hat{\lambda}_{t}-\beta'\hat{R}_{t}+\gamma\hat{\pi}_{t+1} \quad \text{(LL. 4)}$$

$$\hat{c}_{t}=\hat{c}_{t+1}-\chi(\hat{Y}_{t+1}-\hat{X}_{t+1})+\chi\frac{(1-\delta-\psi)}{(1-\delta)}[\frac{\hat{K}_{t+1}-\delta\hat{I}_{t+1}}{(1-\delta)}]+\frac{\psi}{(1-\delta)}(\hat{I}_{t}-\gamma(1-\delta)\hat{I}_{t+1}) \quad \text{(LL. 5)}$$

2. Aggregate supply

$$\hat{Y}_{t+1}=\hat{A}_{t+1}+\nu\hat{h}_{t}+\mu\hat{K}_{t}+\alpha(1-\nu-\mu)\hat{L}'_{t+1}+(1-\alpha)(1-\nu-\mu)\hat{L}''_{t+1} \quad \text{(LL.6)}$$

$$\hat{Y}_{t}=\hat{X}_{t}+\eta\hat{L}''_{t}-\hat{\lambda}''_{t}-\hat{R}_{t} \quad \text{(LL.7)}$$

$$\hat{Y}_{t}=\hat{X}_{t}+\eta\hat{L}'_{t}+\hat{c}'_{t} \quad \text{(LL.8)}$$

$$\hat{\pi}_{t}=\beta' E_{t}\hat{\pi}_{t+1}-\kappa\hat{X}_{t}+\hat{u}_{t} \quad \text{(LL.9)}$$

3. Housing market

$$\hat{q}_t = \gamma_e \hat{q}_{t+1} + (1-\gamma_e)(\hat{Y}_{t+1} - \hat{h}_t - \hat{X}_{t+1}) + m_e(\hat{\lambda}_t + \hat{\pi}_{t+1} + \hat{c}_{t+1}) + \hat{c}_t - \hat{c}_{t+1} \quad \text{(LL.10)}$$

$$\hat{q}_t = \hat{c}''_t - \beta''\hat{c}''_{t+1} + \hat{j}_t(1-\beta''-m_h) - \hat{h}''_t(1-\beta''-m_h) + m_h(\hat{\lambda}''_t + \hat{\pi}_{t+1} + \hat{m}_t'')$$

$$+\hat{q}_{t+1}(\beta''+m_h) \quad \text{(LL.11)}$$

$$\hat{q}_t = \beta'\hat{q}_{t+1} + \hat{c}'_t - \beta'\hat{c}'_{t+1} + (1-\beta')(\hat{j}_t - \hat{h}'_t) \quad \text{(LL.12)}$$

$$0 = h\hat{h}_t + h'\hat{h}'_{t+1} + h''\hat{h}''_{t+1} \quad \text{(LL.13)}$$

4. Borrowing constraint and LTV ratio evolution

$$\hat{b}_t = \hat{q}_{t+1} + \hat{h}_t + \hat{\pi}_{t+1} - \hat{R}_t \quad \text{(LL.14)}$$

$$\hat{b}''_t = \hat{q}_{t+1} + \hat{\pi}_{t+1} + \hat{h}''_t - \hat{R}_t \quad \text{(LL.15)}$$

$$\hat{m}_t'' = q(\phi/m'')\hat{q}_{t+1} \quad \text{(LL.16)}$$

5. Evolution of others state variables

$$\hat{K}_{t+1} = \hat{K}_t(1-\delta) + \delta \hat{I}_{t+1} \quad \text{(LL.17)}$$

$$(\frac{b}{Y})\hat{b}_{t+1} = (\frac{c}{Y})\hat{c}_{t+1} + (\frac{qh}{Y})(\hat{h}_{t+1} - \hat{h}_t) + (\frac{I}{Y})\hat{I}_{t+1} + (\frac{Rb}{Y})(\hat{R}_t + \hat{b}_t - \hat{\pi}_{t+1})$$

$$-(1-s'-s'')(\hat{Y}_{t+1} - \hat{X}_{t+1}) \quad \text{(LL.18)}$$

$$\frac{b''}{Y}\hat{b}''_{t+1} = \frac{c''}{Y}\hat{c}''_{t+1} + \frac{h''q}{Y}(\hat{h}''_{t+1} - \hat{h}''_t) + \frac{Rb''}{Y}(\hat{R}_t - \hat{\pi}_{t+1} + \hat{b}''_t) - s''(\hat{Y}_{t+1} - \hat{X}_{t+1}) \quad \text{(LL.19)}$$

6. Monetary policy

$$\hat{R}_{t+1} = r_R \hat{R}_t + (1-r_R)[(1+r_\pi)\hat{\pi}_t + r_Y \hat{Y}_t] + \hat{e}_{R,t} \quad \text{(LL.20)}$$

7. Shock processes

$$\hat{j}_{t+1} = \rho_j \hat{j}_t + \hat{\epsilon}_{j,t+1} \quad \text{(LL.21)}$$

$$\hat{u}_{t+1} = \rho_u \hat{u}_t + \hat{\epsilon}_{u,t+1} \quad \text{(LL.22)}$$

$$\hat{A}_{t+1} = \rho_A \hat{A}_t + \hat{\epsilon}_{A,t+1} \quad \text{(LL.23)}$$

with $\kappa = (1-\theta)(1-\beta'\theta)/\theta$, $m_h = m''(\beta' - \beta'')$, $m_e = m(\beta' - \gamma)$, $\chi = 1 - \gamma(1-\delta)$ and $\gamma_e = \gamma + m(\beta' - \gamma)$.

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