

Monetary Policy Transmission via Risk-taking Channel in the Mortgage Market

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The views expressed in this paper are solely my own and should not be interpreted as reflecting the views of the Bank of Korea.

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1. Background

2. Two Themes and Methodology

3. Empirical Findings for Risk-taking Channel

4. Analysis of MP Transmission

Background

- Observed facts in the U.S. mortgage market before the sub-prime crisis
 - ▶ Deterioration in lending standards(e.g. : Increases in lending to borrowers not previously qualified)
 - ▶ Applying highest LTV ratio allowed
- All these imply mortgage lenders' aggressive risk-taking
- Then a question follows: what drove them to take more risk?

Risk-taking channel of monetary policy

- Risk-taking channel hypothesis: Causal link between low policy interest rates and risk-taking of lenders

the risk-taking channel in the transmission mechanism (is) defined as the impact of changes in policy rates on either risk perceptions or risk-tolerance and hence on the degree of risk in the portfolios, on the pricing of assets, and on the price and non-price terms of the extension of funding (Borio and Zhu, 2008,2012)

- Preconditions for the channel to operate: **Low policy rates** for **too long** under **favorable economic environment**
- Empirical findings ensued corroborating the existence of risk-taking channel (Jiménez et. al., 2008,2014; Altunbas et. al.,2010, and many others)

■ Motivation: Applying risk-taking channel to the mortgage market

■ Two themes of paper

- First, does easing of monetary policy tend to abet mortgage lenders' risk-taking in the U.S.?
- Second, if so, in the model economy in which the risk-taking channel is operative, does a positive monetary policy shock generate more volatile paths of housing prices and economic activities?

Motivation: Importance of the themes

- ✓ Answers to those two questions shed light on the following issues surrounding the sub-prime crisis
- Role of monetary policy stance in engendering the housing boom
 - ▶ If **yes** to the first question, low policy rates increased mortgage supply not only through price channel but also through risk-taking channel and thus enlarged the housing boom further
- Reason for failure to estimate full magnitude of monetary policy impacts on the housing market and the economy on the whole
 - ▶ If **yes** to the second question, as a result of **neglecting the impacts through risk-taking channel**, central bankers failed to forecast the full effects of monetary policy decisions on the housing market and overall economy

Methodology to explore the two themes

- Regarding the first: Checking empirically whether LTV ratio responded negatively to policy rates in U.S.
 - * LTV ratio chosen as a measure for lenders' risk-taking based on the consideration that LTV ratio may tend to rise in case of lenders' high risk-tolerance and low-risk perception caused by low policy rates
- Regarding the second
 - First step: Incorporating the risk-taking channel based on the empirical finding into the model economy featuring housing market and borrowing constraint
 - Second step: Checking differences between the model economies with and without risk-taking channel in the effects of an accommodative monetary policy shock on housing prices and other key economic variables
 - * Endogenizing LTV ratio in a general equilibrium framework enables us to analyze the effects of the risk-taking channel from the perspective of overall economy

Empirical evidence

■ Monetary policy rates and LTV ratio

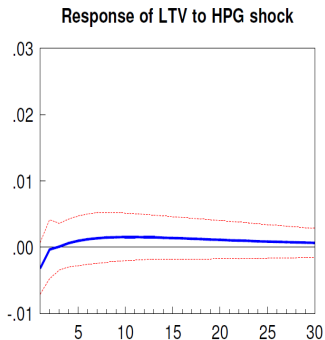
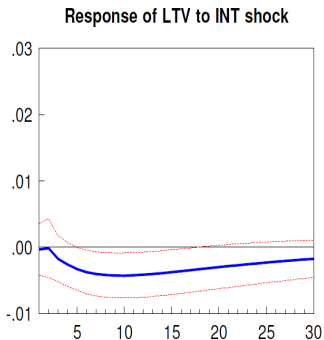
► Simple Regression: Demeaned version

- Data : U.S. 1995 Q1 - 2007 Q2
- Data source : LTV data from Duca *et. al.* (2011), Fed, FHFA
- Result: $LTV_t = 0.33^{***} LTV_{t-1} - 3.21^{***} FFR_{t-1} + 0.18^* HPG_{t-1} + \epsilon_t$
 $DW = 2.21, \bar{R}^2 = 0.79$

► VAR

- $\Gamma y_t = c + A(L) y_{t-1} + \Sigma e_t$
- $y_t = [INT_t, HPG_t, LTV_t]$
- INT : Federal Funds Rates, HPG : percent change of house price index,
 LTV : LTV ratio

Empirical evidence: IRF of LTV to INT & HPG



Model features

- ✓ Skipping details of model to save time and highlight insights as well
- Employing a workhorse DSGE model in the research on housing developed by Iacoviello(2005) featuring housing market and borrowing constraint
 - ▶ But simplifies the original model to adapt it to the purpose of focusing on home mortgage market(e.g. : omission of entrepreneur block in the model)
- Distinctions between the model and standard NK DSGE model
 - ▶ **Housing** exists in the economy to consider housing market fluctuations by replacing durables with housing in existing NK model
 - ▶ **Heterogeneous households**: patient(savers) and impatient(borrowers) whose time preference for current consumption is stronger than that of former
 - ▶ **Borrowing constraint of impatient households**: borrowing amount is constrained by housing value

Fixed LTV ratio in borrowing constraint

■ Impatient household's problem: Exogenous LTV ratio

$$\begin{aligned} \max E_o \sum_{t=0}^{\infty} \gamma^t (\ln c_t + \ln h_t - \frac{(L_t)^\eta}{\eta} + \chi \ln \frac{M_t}{P_t}) \\ \text{s.t. } c_t + q_t(h_t - h_{t-1}) + \frac{R_{t-1}b_{t-1}}{\pi_t} = b_t + w_t L_t + T_t - \Delta(\frac{M'_t}{P_t}) \\ b_t \leq m E_t(\frac{q_{t+1}h_{t+1}\pi_{t+1}}{R_t}) \\ \text{where } m \in (0, 1) \text{ and } \gamma < \beta \text{ for binding borrowing constraint around SS} \end{aligned}$$

- Notations: γ & β (discount factors of impatient and patient households respectively), m (LTV ratio), c (real consumption), h (housing), b (real debt), q (real house prices), L (labor), M (money balances), P (price), π (inflation), R (nominal interest rate), T (transfers from CB)

■ m is fixed at 0.87 in Iacoviello(2005). Hence, borrowing of impatient households depends solely on the present value of housing

Variable LTV ratio in borrowing constraint

- If m responds to R_t set by CB through risk-taking channel, the borrowing constraint changes to

$$b_t \leq m_t E_t \left(\frac{q_{t+1} h_t \pi_{t+1}}{R_t} \right)$$

- Then, borrowing depends not only on **housing** value but also on **LTV ratio** reacting negatively to interest rates.

Endogenizing LTV ratio

■ Baseline model: $m = 0.87$

■ Risk-taking model

▶ Backward-looking LTV ratio decision rule

$$\hat{m}_t = 0.7\hat{m}_{t-1} - 3.2\hat{R}_{t-1} + 0.3\hat{q}_{t-1} + \epsilon_t$$

▶ Forward-looking LTV ratio decision rule

$$\hat{m}_t = -1.95\hat{R}_t + 0.2\hat{q}_t - 1.77E_t(\hat{R}_{t+1}) + 0.2E_t(\hat{q}_{t+1}) + \epsilon_t$$

* The coefficients in the forward-looking rule are estimated using the same data used for estimating the backward-looking rule.

Transmission of risk-taking channel through mortgage

- Interest Rate Channel (standard type in NK)

Positive MP shock $\longrightarrow R_t \downarrow \longrightarrow rr_t \downarrow \longrightarrow c_t \uparrow$

- Collateral Channel (Kiyotaki and Moore, 1997)

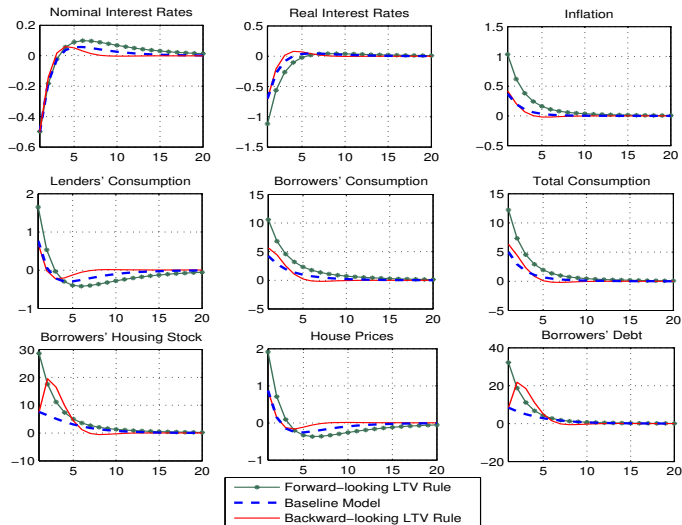
Positive MP shock $\longrightarrow R_t \downarrow \longrightarrow q_t \uparrow \longrightarrow b_t \uparrow \longrightarrow c_t \uparrow$

✓ Those two channels have been considered in analysis of monetary policy impacts.

- **Risk Taking Channel**

Positive MP shock $\longrightarrow R_t \downarrow \longrightarrow m_t \uparrow \longrightarrow b_t \uparrow \longrightarrow q_t \text{ \& } c_t \uparrow$

Comparison of IRFs



Implications

- For analysis of monetary policy impacts: Need to consider amplification of effects of monetary policy decisions through risk-taking channel in the mortgage market
 - ▶ Beneficial for forecasting and optimal policy decisions
- Scope for smoothing fluctuations in housing prices and pass-through impacts of housing market on economic activities through regulation on LTV ratio

Monetary policy transmission via risk-taking channel in the mortgage market

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Abstract

This paper aims to analyze the transmission of accommodative monetary policy to the overall economy through the risk-taking channel operating in the mortgage market. To achieve this aim, the analysis procedure undergoes two steps. Firstly, the empirical relationship between short-term interest rates and LTV ratio is estimated using the U.S. data to verify the existence of the risk-taking channel. Secondly, the estimated relationship is incorporated into a DSGE model featuring a borrowing constraint and housing to construct the virtual economy in which the channel takes effect to analyze the impacts of a monetary policy shock on it. The results of the analysis suggest that under a low interest rate environment, the effects of the risk-taking channel should be taken into account in monetary policy analysis as it amplifies the impacts of a monetary policy shock. Furthermore, there is a scope for policy authorities to smooth both real and financial volatilities by lowering a ceiling on LTV ratio to discourage excessive risk-taking.

JEL Classification: E32, E42, E51, E52

Keywords: Risk-taking channel, Monetary policy, LTV ratio, Borrowing constraint

국문 초록

본 논문의 목적은 모기지(mortgage) 시장에서 작동하는 위험부담경로(risk-taking channel)를 통해 통화정책이 전체 경제에 미치는 영향을 분석하는 데 있다. 이를 위한 분석 절차는 두 단계로 구성된다. 첫 번째 단계에서는 미국 모기지 시장에서 위험부담경로가 존재하는지 여부를 검증하기 위해 단기 이자율과 LTV 비율 간의 실증적 관계를 추정한다. 두 번째 단계에서는 첫 번째 단계에서 추정된 관계식을 차입제약과 주택을 특징으로 하는 DSGE 모형에 반영함으로써 위험부담경로가 작동하는 가상경제를 모형화하고, 이를 이용하여 통화정책 충격이 전체 경제에 미치는 영향을 분석한다. 동 분석의 결과로부터 다음과 같은 시사점을 도출할 수 있다. 첫째, 저금리 상황에서는 위험부담경로가 통화정책 충격의 영향을 증폭시키기 때문에 통화정책의 파급효과 분석 시 동 경로를 통한 영향을 추가적으로 고려할 필요가 있으며, 둘째, 정책당국이 과도한 위험부담을 억제하기 위해 LTV 비율 상한을 하향 조정함으로써 실물 및 금융 변동성이 완화될 여지가 있다.

JEL 분류: E32, E42, E51, E52

핵심주제어: 위험부담경로, 통화정책, LTV 비율, 차입제약

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1 Introduction

It has been maintained that the deregulation and liberalization of housing finance since the 1980s have broadened credit availability which in turn has led to more pronounced fluctuations in housing prices. Specifically, banks and governmental mortgage agencies were allowed under the liberalization process to produce a wide range of mortgage loan products, set lending interest rates at their own discretion, determine the level of the loan-to-value (LTV) ratio based on their own judgement rather than regulatory prescriptions, and so forth. Moreover, non-bank financial corporations were given permission to enter the mortgage market, thereby heightening the degree of competition in this market.¹ Consequently, easier credit supply to the housing market has increased the volatility of the demand for housing and house prices, and in turn amplified further repercussions of the housing sector on consumption and residential investment. These developments in housing finance retain substantial implications for the analysis of monetary policy transmission. Recent findings support the view that the financial liberalization process has rendered the housing sector and the rest of the economy more responsive to a monetary policy shock as interest rates affect credit availability more significantly in a deregulated environment (Iacoviello and Minetti, 2003; IMF, 2008; Calza *et al.*, 2009).^{2 3}

The aforementioned findings are obtained under an assumption that mortgage market characteristics are exogenously determined by the financial deregulation process. Recently, a line of research has raised the issue of a possible causal link between an accommodative monetary policy stance and bank lending behavior. Researchers pursuing this line of reasoning highlight the observed facts regarding lending markets in the run-up to the recent housing boom which numerous developed countries underwent. During that period, lending criteria were loosened appreciably, the minimum down-payment decreased considerably while policy rates were deemed relatively lower than a specific judgement criterion, for example, the Taylor rule or estimated neutral interest rates. The crux of the findings of these researchers is that low interest rates for such a protracted period increased banks' appetite for higher risk in lending and other investments. This transmission channel of monetary policy is labeled the *risk-taking channel* by Borio and Zhu (2008). However, the underlying rationale for the *risk-taking channel* has been highlighted by central bankers. Greenspan (2010), for example, ascribes the failure of the banking system during the re-

¹ The characteristics of housing finance in each country is distinct. IMF (2008) and Calza *et al.* (2009) provide indicators of the differing developments in mortgage financing in industrialized countries. ECB (2009) surveys the recent circumstances of housing finance in the Euro area since 1999.

² Regardless of the recognized importance of credit availability in housing finance, there exist a limited number of findings about the relationship between credit availability and house prices. The reason for this is that there are few trustworthy measures of *credit availability* itself. Even though the amount of mortgage debt seems a plausible proxy for the variable, the amount registered in banks' books is not a proper measure since it is the realized value of *credit availability*. Furthermore, changes in mortgage depend on other factors besides it.

³ Another relevant finding is in Almeida *et al.* (2006) which confirms that the response of house prices to income shocks is more rapid in those countries having a higher ceiling on the LTV ratio.

cent financial crisis to the possibility that the prolonged period of a relaxed policy stance might have driven banks to neglect the negative tail of investment risk (Greenspan, 2010); this comment implies that the overall perception of risk was positively biased. Voices from the European Central Bank (ECB) have expressed apprehension from a similar viewpoint; low interest rates for a prolonged period abet moral hazard in banks' investments imbuing them with a myth that the central bank may not be able to reverse interest rates rapidly because of worries about asset market collapse (ECB, 2005; Trichet, 2005; Papademos, 2006).⁴

These reflections provide a motivation to consider the relationship between low interest rates and banks' risk taking attitude. I submit the hypothesis that a positive monetary policy shock causes banks to raise the LTV ratio and supply ample liquidity to the housing market, thereby rendering the path of house prices and consumption more volatile. In a nutshell, this paper has two aims: firstly, to verify the existence of the risk-taking channel in the mortgage market, and secondly, to estimate the repercussions of an expansionary monetary policy shock on the economy as a whole via this channel. These aims are attained through a two-stage analysis. To examine the existence of the *risk-taking channel*, namely, a negative relationship between monetary policy rates and the LTV ratio, two kinds of empirical analyses, i.e. regression and VAR, are conducted using U.S. time series data. Although there are various indicators of the degree of banks' risk-taking, the LTV ratio is chosen as an effective one as mortgage lenders tend to set the ratio depending on their own perception of the risk latent in housing-collateralized lending. Subsequently, a DSGE model is developed incorporating an estimated regression equation for the *risk-taking channel* to analyze its role in a broader economy. In the DSGE model, the LTV ratio is defined as a function of policy rates and house price inflation and is set less than unity. This variable plays a key role in amplifying and propagating an initial shock to the economy.⁵ In addition, the model follows the lead of Iacoviello (2005) and Iacoviello and Neri (2010). These papers adapted the financial accelerator mechanism of Kiyotaki and Moore (1997) to investigate the dynamics of the housing sector and its spillover into the rest of the economy.

There are two notable contributions in this paper which set it apart from the rest of the literature on bank risk-taking and financial friction in lending. Firstly, this analysis is the first attempt, to the best of my knowledge, to delve into the effects of the *risk-taking channel* employing a general equilibrium framework. Secondly, the model in this paper *endogenizes* the LTV ratio for the first time.

To elaborate on the second point, the LTV ratio in existing models is assumed to be a

⁴ The government's intervention to relieve troubled banks through bailout programs also has been referred to as a cause of the 'too big to fail' myth.

⁵ The ceiling on the LTV ratio in practice can exceed one, as in the U.S. which raised the maximum ratio up to 125%. However, only a small portion of borrowers can take advantage of this ceiling as other income requirements and lending criteria should be satisfied.

fixed constant (Monacelli, 2008; Calza *et al.*, 2009; Iacoviello and Neri, 2010). An improvement over the constant LTV ratio is the assumption of a time-varying exogenous stochastic process as in Pariés & Notarpietro (2008) and Gerali *et al.* (2010), but still this stochastic ratio is not affected by other variables in the model. However, in practice, since banks adjust the LTV ratio on the basis of an evaluation of default risk and the redeemable value of collateral in case of foreclosure, the existing way of treating the LTV ratio in economic models is clearly unsatisfactory. Endogenizing this ratio bases the model more firmly on realistic aspects of housing finance. An additional advantage of introducing the LTV ratio in this manner is the resultant parsimony of the model. As opposed to the models in, for instance, Goodfriend and McCallum (2007), Cúrdia and Woodford (2008), and Gerali *et al.* (2010) which introduce a separate block for financial intermediation, the supply side of credit can be reflected in my model by allowing the LTV ratio to vary depending on the banks' decision.

The main findings of the analysis are twofold. First, the results from the regression and VAR analysis lend firm support to the assertion that there is a negative relationship between short-term interest rates and the LTV ratio. It implies mortgage suppliers have tended to be more aggressive in housing-collateralized lending in the period of low interest rates. Secondly, a positive monetary policy shock in the model with the *risk-taking channel* included produces enhanced deviations of consumption and financial debt from the steady state than the model without this channel. These findings can shed light on the conundrum why central bankers, before the sub-prime crisis, failed to forecast the catastrophic results stemming from low interest rates for a prolonged period; presumably they dismissed the *risk-taking channel* when analyzing the transmission effects of their monetary policy decisions. Furthermore, the results justify the need for central banks to pay more attention to the possible existence of more as yet undiscovered transmission channels of monetary policy and for financial supervisory authorities to regulate banks' risk-taking behavior.

The remainder of this paper is organized as follows. Section 3.2 provides a brief review of the rationale for, and summarises existing findings on, the *risk-taking channel*. It also presents an explanation for the working of the *risk-taking channel* in bank lending and its repercussions on the housing market and broader economy. In section 3.3 empirical evidence for the *risk-taking channel* in the U.S. mortgage banking sector is presented. In section 3.4, a baseline DSGE model is developed and, in the following section, the monetary policy transmission is analyzed in the absence of the *risk-taking channel*. In section 3.6, the *risk-taking channel* is accommodated in the baseline model to examine how the transmission effects change in the presence of the channel. Section 3.7 sets out the conclusion.

2 Risk-taking Channel and Mortgage Lending

This section provides a short summary of the theoretical considerations underlying the *risk-taking channel* and summarises relevant empirical findings. I will then demonstrate the implications of the channel for the mortgage market and its impact on the housing market and the economy as a whole.

2.1 Rationale and Empirical Findings

The *risk-taking channel* was introduced explicitly by Borio and Zhu (2008) as an additional monetary policy transmission channel. It is defined as follows:

the *risk-taking channel* in the transmission mechanism (is) defined as the impact of changes in policy rates on either risk perceptions or risk-tolerance and hence on the degree of risk in the portfolios, on the pricing of assets, and on the price and non-price terms of the extension of funding. (*Ibid*, pp. 9)

This issue has received growing interest in academia due to the failure of the global banking system caused partly by the excessive risk-taking behavior of mortgage suppliers observed in the first half of the last decade. The Fed maintained that the overheated housing market prior the crisis was not associated with past monetary policy decisions (Greenspan, 2010; Bernanke, 2010). However, an alternative possibility was proposed that an accommodative monetary policy stance for the extended period might affect the risk-taking behaviour of economic agents, especially financial intermediaries. Thereafter, the main focus has been on the causal chain or correlation between an easy policy stance and banks' risk-taking. A preliminary consensus has been established that two necessary conditions must be fulfilled: 'too low' interest rates as the first condition and for 'too long' a period as the second one.

The question naturally follows: in what ways does a loose monetary policy stance encourage banks to take more risk? There are three possibilities. The foremost and fundamental driver, from my viewpoint, would be the tendency of 'search for yield' in the period of low interest rates as noted by Rajan (2006) and others. To take an example from the banking sector⁶, the yields of bonds are more likely to be lower than these of other investments such as stock and collateralized lending to households. While the exposure to stock is circumscribed within a certain level since it is classified as a highly risky asset and hence harmful for satisfying minimum capital requirements set by the BIS (Bank for International Settlements), collateralized lending ensures higher profitability and also limited possible loss in the case of default. These two attractions drive banks to expand lending against housing as collateral by loosening lending criteria and increasing lending to borrowers with low creditworthiness.

⁶ Investment banking or shadow banking is not considered in this example.

Secondly, during a period of low monetary policy rates coupled with moderate economic growth as during the Great Moderation, banks are more likely to neglect the possibility that assets held by them can turn sour or non-performing and borrowers' real income growth can become negative in the future. To apply this reasoning to the mortgage market, if the value of collateral and the income level of borrowers were increasing, then mortgage suppliers would perceive the risk in lending as lower than they would otherwise. The underestimation of risk results mainly from the expectation that robust growth in income and collateral value will persist into the distant future. Finally, as pointed out by the ECB sources, banks are more likely to undertake riskier and more profitable investments as long as interest rates remain low in the belief that the lender of last resort will come to the rescue in order to prevent the overall economy from collapsing. If it were not for the 'too big to fail' myth, preference for a riskier position could be subdued to some extent and the degree of moral hazard could be lessened.⁷

Empirical findings on the *risk-taking channel* has been increasing recently. Drawing on expansive and detailed data on individual bank loans from the Spanish Credit Register in the period from 1984 to 2006, Jiménez *et al.* (2008) find that lower overnight lending rates cause banks to loosen lending criteria and expand credit line to borrowers with mediocre credit records despite higher default risk. These findings gain support from Ioannidou *et al.* (2009) who provide the evidence that the default probability of bank loans rises and lending to riskier borrowers tends to increase in Bolivia as the U.S. federal funds rates (FFR) decrease.⁸ In another study, Altunbas *et al.* (2010) investigate whether low interest rates affect the risk position of 643 banks in 15 industrialized countries using balance sheet data for the period from 1998 to 2008. Banks' risk is measured by the expected default frequency (EDF), an indicator for the probability that a company will default in a certain time horizon. They find that the low short-term interest rates for a sustained period caused an increase in banks' default risk. Gambacorta (2009) provides evidence on the negative relationship between interest rates and banks' default risk by using an econometric approach similar to the one employed in Altunbas *et al.* (2010).⁹ Delis and Kouretas (2011), by consulting the balance sheet information of banks in the Euro area during the period 2001-2008, find that the ratio of risky asset value to total asset value, as well as the ratio of non-performing loans to total loans, increased. Maddaloni and Peydró (2011) focus explicitly on the influence of monetary policy rates on relaxed lending standards. By using the responses from bank lending surveys carried out in the Euro area and U.S., they identify the positive influence of an accommodative policy stance on the loosening of lending standards during the period from 2002 Q4 to 2008 Q3.

⁷ Essentially the first and second points are in line with Borio and Zhu (2008) who explain how the *risk-taking channel* works in general instead of focusing on bank lending.

⁸ The authors maintain that the U.S. FFR is a proper measure of Bolivian monetary policy stance since over 90 percent of Bolivian deposits and credits are transacted in the U.S. dollar.

⁹ The data used is obtained from the balance sheets of 600 banks in Europe and U.S. during the period 2007-2008.

A similar strand of research in the U.S. has also recently been in the spotlight. Adrian and Shin (2009, 2010b) stress the importance of the role of short-term interest rates in generating business cycle by causing dramatic changes in the banking sector's credit supply. In a recent paper, Adrian and Shin (2010a) introduce the concept of *risk-taking channel* and maintain that banks are liable to estimate risk as lower and hence take a riskier investment position as lower short-term interest rates widen the margin between the interest rate on deposits and return on the assets in the balance sheet. However, their research is theoretical and hence needs sound support from empirical research.

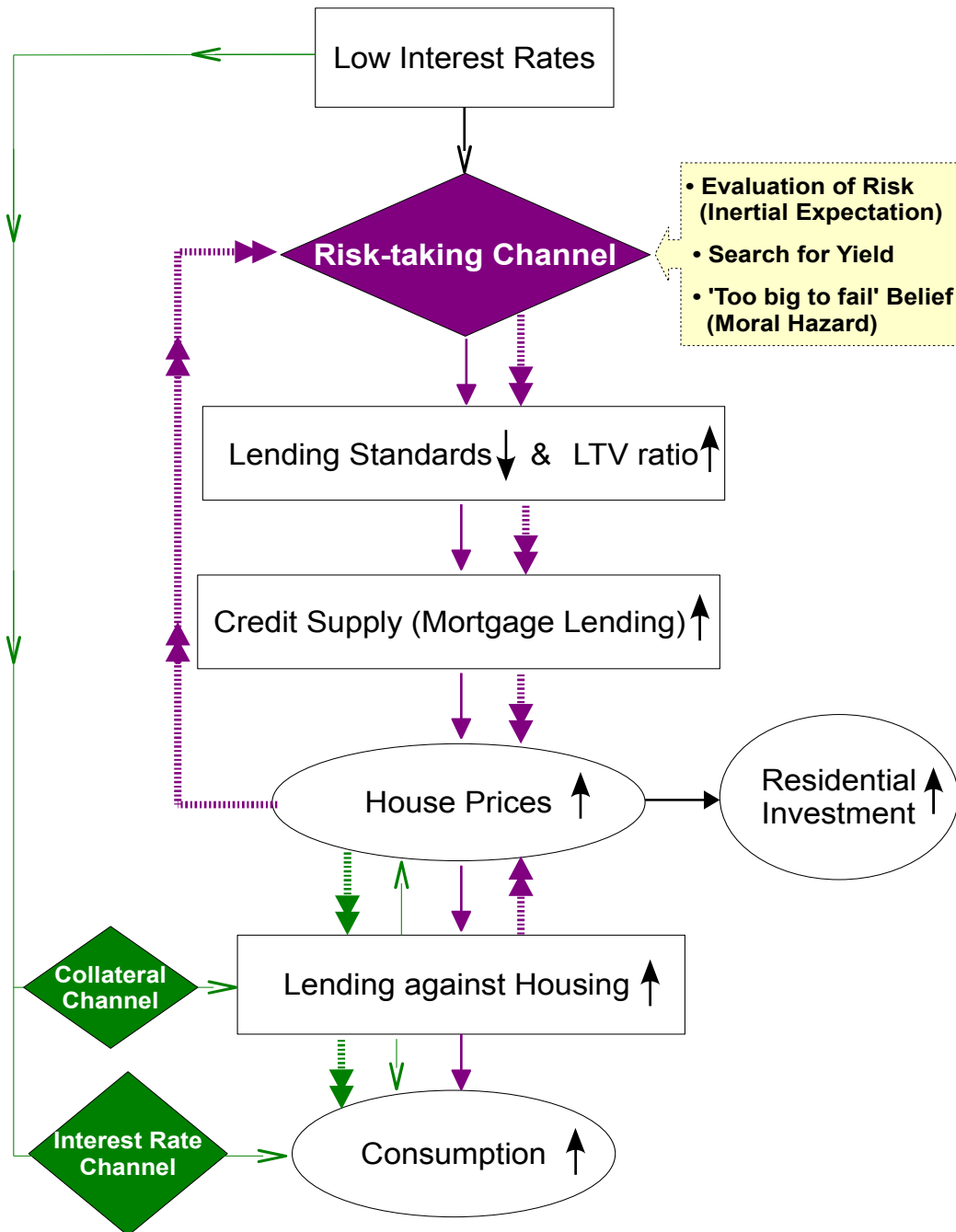
2.2 Implications of Risk-taking Channel for Mortgage Market and Economy

The empirical studies reviewed in the previous sub-section suggest that lower interest rates lead banks to soften lending criteria and supply more credit than they would otherwise. The specific dependent variables in these analyses include the probability of banks' default in the future, the ratio of risky asset value to the total asset value and the percentage of banks tightening their lending standards. Given the importance of the effect of leverage on general consumption and housing purchases, the LTV ratio needs to be added to the list of measures of banks' risk appetite. The rationale for considering the LTV ratio as a measure of risk-taking attitude is consistent with the rationale for the *risk-taking channel*. During a prolonged period of an accommodative monetary policy stance, collateralized lending to households satisfies the dual targets of profitability and safety. This leads banks to expand lending against housing as collateral by raising the LTV ratio even though the collateral value stays constant. There are additional factors inducing banks to lower the LTV ratio. As long as house price inflation triggered by low interest rates continues, lenders would take the default risk of borrowers less seriously compared with the period of a bearish housing market. Furthermore, if low interest rates are maintained for an extended period, expectation of robust house prices in the future would encourage complacency in evaluating the risk of mortgage lending. Lenders can also decrease the price of lending as long as households' net worth is increasing given the low interest rate environment. As such, the realized appreciation of housing prices and expectation about further increases induce banks to perceive the overall risk of mortgage lending as lower and to increase the LTV ratio. Enhanced credit supply and higher value of housing will persist until interest rates reverse their direction.

The *risk-taking channel* operating in the mortgage market has unambiguous implications for the wider economy. More funds would be available to households than in the absence of the channel. The funds borrowed against housing are spent not only on purchasing houses but also on consuming other durable and non-durable goods. Residential investment increases as the demand for housing expands fueled by ampler liquidity with low borrowing costs. Notable is that once the channel begins to operate, a self-reinforcing feedback loop would come into play between risk-taking, mortgage lending supply, house prices and real

economic activity. Figure 1 illustrates the causal chain running from low interest rates to the housing market and macroeconomic activities via the *risk-taking channel*.

Figure 1. Risk-taking Channel in Mortgage Market



Note: 1. Rectangles and ellipses represent changes in financial and real variables respectively.
2. The thick dashed line represents the feedback effects between the risk-taking channel, housing market and mortgage.

3 Empirical Estimation of Risk-taking Channel

In this section, we examine the presence of the *risk-taking channel* in the U.S. mortgage market. Two empirical methodologies are employed: simple regression and VAR approach. However, before conducting the analysis, we first discuss some relevant aspects of the data on the LTV ratio.

3.1 Data

There does not exist an officially compiled historical series on the LTV ratio. Hence, one has to depend on work done by other researchers to obtain this database. In this regard, a special comment should be given about the LTV time series estimated by Duca *et al.* (2011) for first-time home buyers in the U.S. The series is very useful for researchers in the field of housing since the frequency is very high (quarterly) and the time span extends as far back as 1979.¹⁰ The estimated data can be broadly classified into two types depending on the type of mortgage issuers; private mortgages and all types of mortgages including those from government-sponsored agencies such as the Federal Housing Finance Agency (FHFA). The series for private mortgages is considered more pertinent for an analysis of the *risk-taking channel* since the mortgages from the FHFA omit non-standard loans which convey substantial information on the risk-taking behavior of private mortgage lenders.

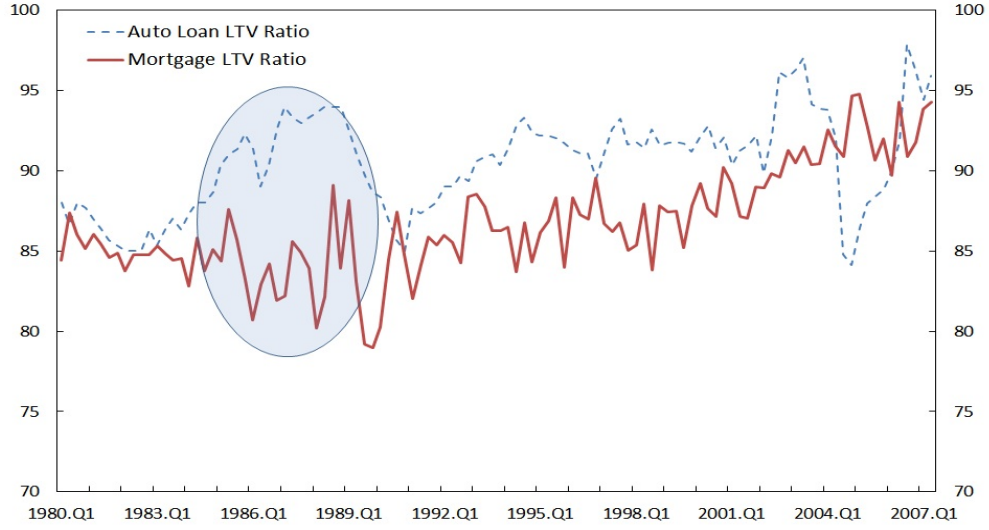
The data series has proven to be highly reliable judging by its close co-movement with the data on the auto loan LTV ratio published officially by the Fed.¹¹ The property of an automobile as a durable good justifies the comparison. Figure 2 shows the long-term series of the two kinds of LTV ratios regarding home mortgages and auto loans, respectively, from 1980 Q1 to 2007 Q4. These two time series appear to have an upward trend, although there is pronounced decoupling between them during the period from 1985 to 1989. Especially after 1990, the co-movement of the two trends is pronounced in the same figure.

To evaluate the correlation between the trends of both time series, the trend components of each time series are extracted using the Hodrick-Prescott (HP) filter with the smoothing parameter 100,000. The trend components are graphed in Figure 3. Not surprisingly, and as expected from the original data series, the correlation coefficient turns out to be 0.9930 which implies a near perfect co-movement. This lends great plausibility to the data series estimated by Duca *et al.* (2011) and we will use this in our subsequent estimations.

¹⁰Using the estimated data, the paper evaluates the influence of credit condition changes on house prices.

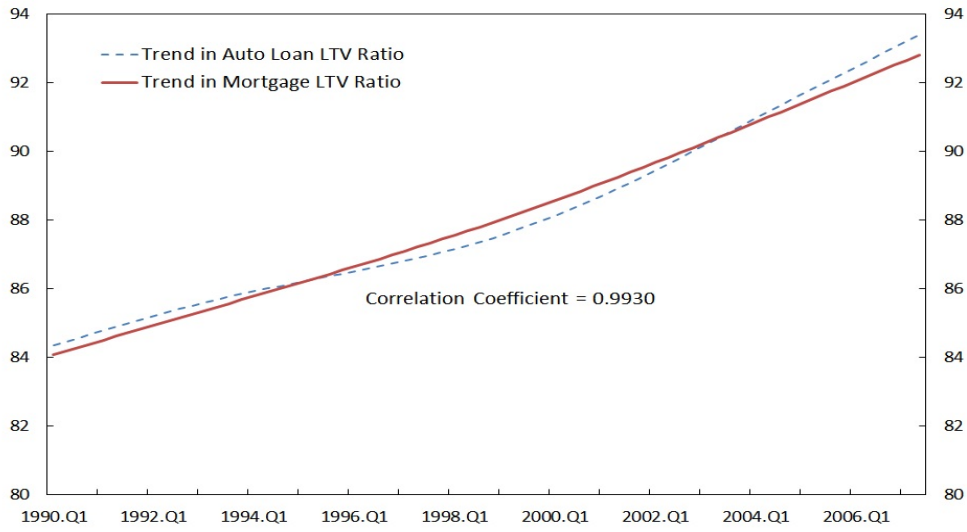
¹¹The data can be downloaded from the 'Terms of credit' menu on the webpage of <http://www.federalreserve.gov/releases/g19/hist>

Figure 2. Auto Loan and Home Mortgage LTV Ratio in U.S.



Data Source: Federal Reserve, Duca *et al.* (2011)

Figure 3. Trend Components of Auto Loan and LTV Ratio



Data Source: Federal Reserve, Duca *et al.* (2011)

3.2 Estimation

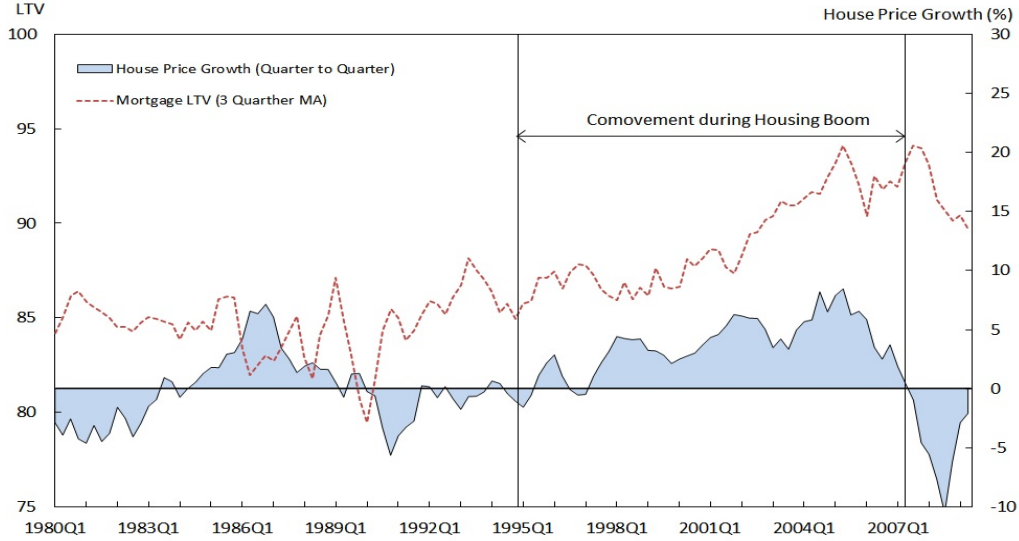
Regression Analysis

To examine whether the *risk-taking channel* exists or not in the U.S. mortgage market, that is, if lenders take on more risk by increasing the LTV ratio as interest rates decrease, the following regression equation is estimated with the LTV ratio as the dependent variable.

$$LTV_t = \alpha + \beta_1 LTV_{t-1} + \beta_2 FFR_{t-1} + \beta_3 HPG_{t-1} + \epsilon_t \quad (1)$$

The determinants of the LTV ratio in the current period, LTV_t , includes the one-quarter lagged LTV ratio, LTV_{t-1} , the lagged Federal Fund Rates (FFR_{t-1}), which are the overnight interest rates fluctuating closely around policy rates, the lagged growth rates of real house prices, HPG_{t-1} which is computed using the National House Price Index (NHPI) published by FHFA. The equation above hypothesizes that mortgage lenders set the LTV ratio of the current period based on the level of short-term interest rates and house price inflation in the previous period while avoiding overly rapid changes by adjusting the LTV ratio in the previous period to a small extent. The inclusion of house price inflation is justified on the basis of the reasoning about the *risk-taking channel*. As house prices continue to rise for a prolonged period, lenders are more likely to focus on the positive side in the distribution of the housing price risk and hence increase the LTV ratio. The apparent positive correlation in Figure 4 between the house prices and the LTV ratio in the U.S. from 1995 to 2007 seems to support this speculation.

Figure 4. Mortgage LTV Ratio and House Price Growth in U.S.



Data Source: Federal Reserve Board, Duca *et al.* (2011)

The regression results for two different time periods are shown in Table 1. The first time period for estimation is from 1980 Q1 to 2009 Q2 to utilize all the data on the regression variables. The coefficient of FFR_{t-1} , which is of main interest, is significant at the 10% significance level as well as that of HPG_{t-1} . The signs of the coefficients are consistent with the *risk-taking channel* hypothesis above; low interest rates and the robust housing market induce lenders to assume more risk by raising the LTV ratios and become more willing to supply credit.

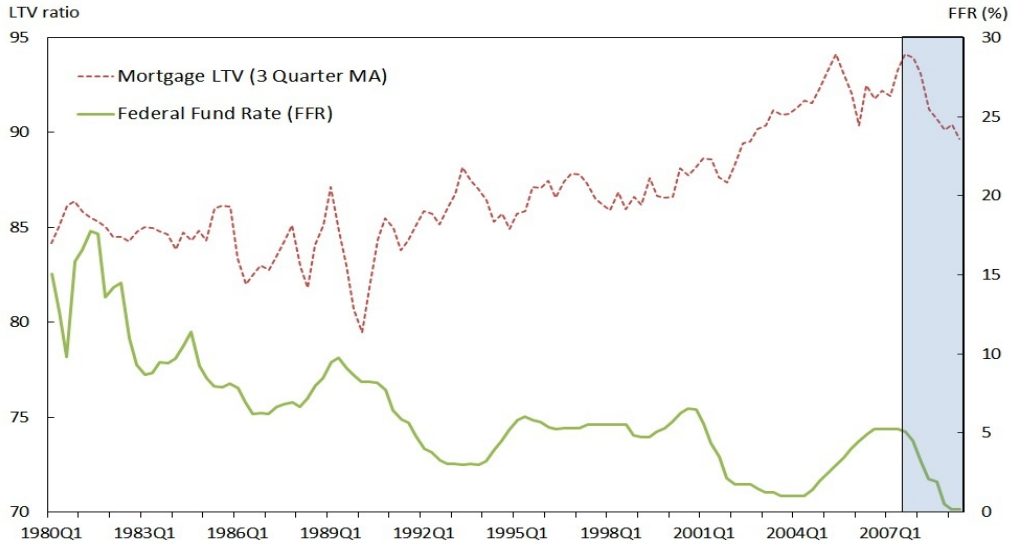
In the regression for the second time period from 1985 Q1 to 2007 Q2, the coefficients

Table 1. Estimation of LTV Equation using Level Data

	1980 Q1 - 2009 Q2			1985 Q1 - 2007 Q2		
	value	<i>t</i> -statistic	<i>p</i> -value	value	<i>t</i> -statistic	<i>p</i> -value
α (constant)	28.855***	4.701	0.000	40.392***	5.124	0.000
β_1 (LTV_{t-1})	0.676***	9.917	0.000	0.558***	6.466	0.000
β_2 (FFR_{t-1})	-0.135*	-1.974	0.051	-0.425***	-3.195	0.002
β_3 (HPG_{t-1})	0.104***	1.729	0.087	0.146*	1.692	0.094
	$R^2 = 0.643$, $DW = 2.283$			$R^2 = 0.649$, $DW = 2.153$		

of these two variables prove to be significant again.¹² Notably, the coefficient of FFR_{t-1} is significant even at the 1% significance level. The statistical significance improves since the new time period excludes the data from 2007 Q2 to 2009 Q2. Over those two years, the housing market crash subdued the LTV ratio despite appreciable decreases in policy rates, as the shaded area in Figure 5 illustrates. Overall, the two sets of regression results corroborate the existence of the *risk-taking channel* in the U.S. and support inclusion of the channel when we inspect the effects of monetary policy decisions on the mortgage market. In terms of macroeconomic modeling, this implies that the LTV ratio should be allowed to vary based on changes in interest rates and house prices to analyze the full aspects of monetary policy transmission.

Figure 5. Mortgage LTV Ratio and Federal Fund Rates in U.S.



Data Source: Federal Reserve Board, Duca *et al.* (2011)

¹²The motivation for starting the sample period from 1985 lies in the possibility that the financial liberalization might begin exerting its real influence only after the mid-1880s. Moreover, the samples after the breakout of the sub-prime crisis are excluded because the relationship between interest rates and house prices in the post-crisis period is positive which is abnormal from the viewpoint of the established empirical findings.

Since the equations estimated using the level data are not suitable for the log-linearized DSGE model to be presented in the following section, a separate equation needs to be estimated using detrended or demeaned data. As the overall fitness of regression using the detrended data by HP filter is not satisfactory, demeaned data are used for all variables in the regression equation. Demeaning implies that the long-term average is assumed to be the steady state of each variable. The regression equation to be estimated is given below.¹³

$$\widehat{LTV}_t = \gamma_1 \widehat{LTV}_{t-1} + \gamma_2 \widehat{FFR}_{t-1} + \gamma_3 \widehat{HPI}_{t-1} + \epsilon_t \quad (2)$$

where the hatted variables represent percentage deviation from the steady state and HPI represents the level of the house price index from the FHFA (instead of the growth rate denoted by HPG in the preceding regression analysis).¹⁴

Table 2. Estimation of LTV Equation using Demeaned Data

	1980 Q1 - 2007 Q2			1995 Q1 - 2007 Q2		
	value	<i>t</i> -statistic	<i>p</i> -value	value	<i>t</i> -statistic	<i>p</i> -value
$\gamma_1 (\widehat{LTV}_{t-1})$	0.427***	4.885	0.000	0.329*	2.012	0.036
$\gamma_2 (\widehat{FFR}_{t-1})$	-0.577	-1.335	0.185	-3.207***	-4.370	0.000
$\gamma_3 (\widehat{HPI}_{t-1})$	0.128***	4.568	0.000	0.181***	6.235	0.000
	$R^2 = 0.676$, $DW = 2.045$			$R^2 = 0.792$, $DW = 2.214$		

Table 2 shows the two sets of regression results for the different time periods. For the first time period from 1980 Q1 to 2007 Q2, the coefficient of $\widehat{FFR}_{t-1}$ turns out to be insignificant even at the 10% significance level, whereas it is highly significant for the second time period from 1995 Q1 to 2007 Q2. Based on the statistical significance, the regression equation for the latter time period is set as the benchmark LTV equation to be incorporated into the DSGE model. To express it in an equation form, the estimated equation of (2) is given by

$$\widehat{LTV}_t = 0.211 \widehat{LTV}_{t-1} - 3.207 \widehat{FFR}_{t-1} + 0.181 \widehat{HPI}_{t-1} + \epsilon_t \quad (3)$$

The estimated coefficients imply that lenders respond more aggressively to the deviation of short-term rates from the steady state than that in house prices. A basic intuition is provided by the fact that the *risk-taking channel* induces low interest rates to influence lenders' behavior in more ways than house prices do. In a low interest rate environment,

¹³ Not only for the purpose of obtaining a dynamic solution to the model but also by the assumption of naive type of backward-looking expectation, the dependent variables take only one-period lagged terms.

¹⁴ A separate regression equation is estimated which includes *realized* federal funds rates instead of *nominal* ones. The estimation results reveal that the magnitude of the coefficient of γ_2 is slightly below the level obtained by the estimation of the equation including nominal FFR . This implies that the regression result is robust.

lenders expect higher house prices, search for higher yield and estimate downside risk to collateral as lower.

The error term, ϵ_t , which is a shock to the LTV decision process, retains an important implication for the housing market. The shock encompasses, for instance, the changes in regulation relating to the discretion of mortgage lenders to decide on their LTV ratios, the invention of new lending products such as exotic mortgages, and changes in the degree of information asymmetry between lenders and borrowers. For example, if the financial authorities grant more latitude to mortgage lenders in determining the LTV ratio or allow them to sell mortgage products with a smaller downpayment, then the ratio will increase given a specific level of house prices and interest rates.

VAR Analysis

A VAR analysis is now employed to examine the existence of the risk-taking channel. A specific representation of the relationship to be identified by VAR will differ from one obtained through regression analysis between the three variables of interest, i.e. short-term interest rates, house prices and the LTV ratios. However, as each variable in a VAR model is also expressed in a similar type of equation to a regression equation with the LTV ratio as a dependent variable, the same qualitative aspect of the *risk-taking channel*, if it exists, can be ascertained through an impulse response analysis. The specific VAR model is defined as below.

$$\Gamma y_t = c + A(L)y_t + \Sigma e_t \quad (4)$$

where y is a vector of endogenous variables, $A(L)$ is the parameter matrix in the lag operator L , and Σ is the variance-covariance matrix of the structural shocks. The vector y includes three endogenous variables, (i) the federal funds rates denoted by INT , (ii) the growth rates of the house price index, HPG , and (iii) the LTV ratio. The model is estimated using the same data as in the regression analysis from 1980 Q1 to 2007 Q2. In order to let the impulse response of the LTV ratio be more sensitive to a monetary policy shock, the data after 2007 Q2 is excluded.

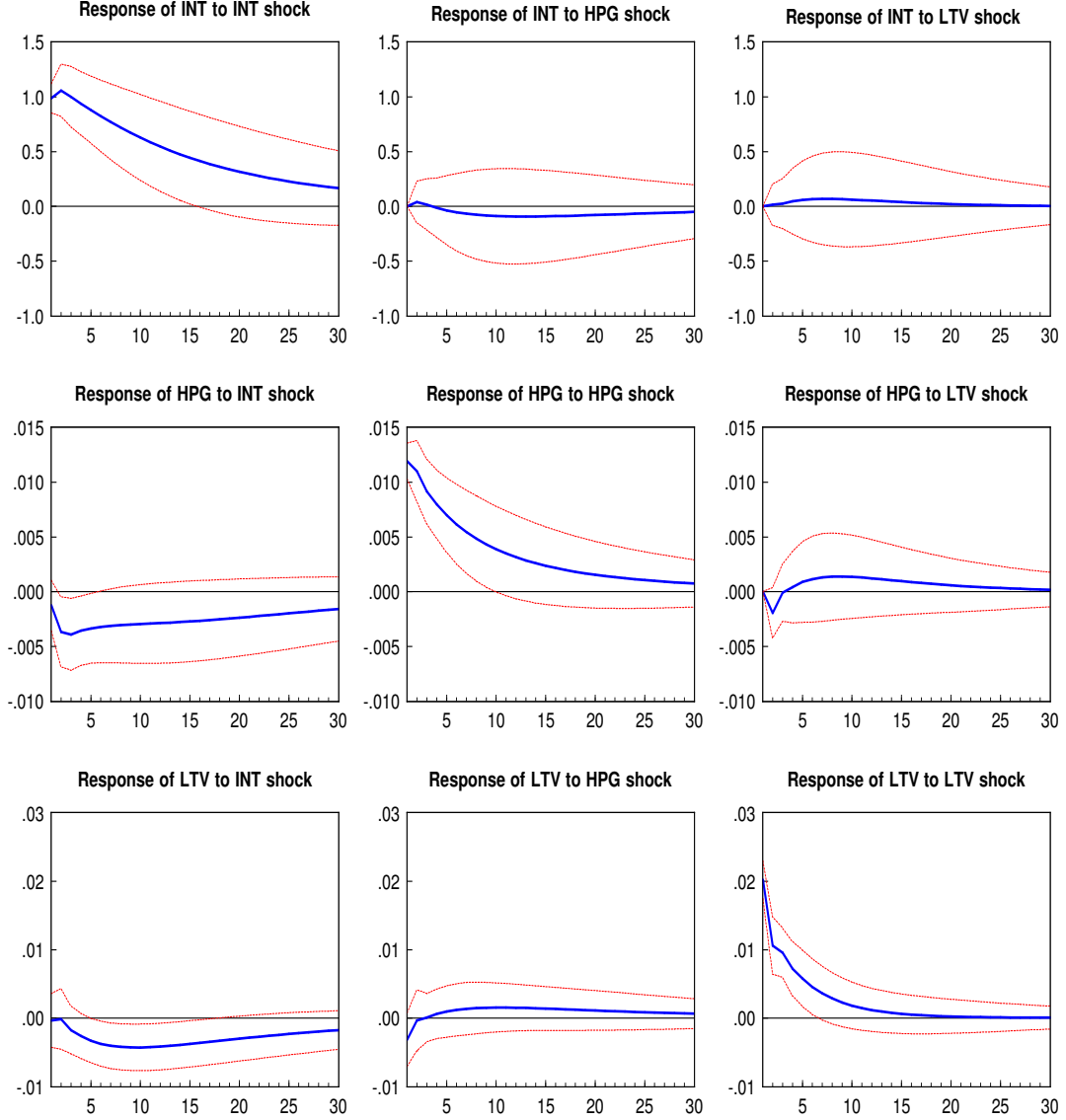
The three structural shocks from the model are identified through Cholesky decomposition which include a monetary policy shock and shocks to house prices and the LTV ratio. The endogenous variables are ordered as follows:

$$y_t = [INT_t, HPG_t, LTV_t] \quad (5)$$

This recursive identification scheme restricts interest rates, INT , from responding contemporaneously to the house price growth (HPG) and the LTV ratio. In a similar vein, the LTV ratio bears no influence on HPG in the same quarter. These restrictions are harmonious with the fundamental purpose of this VAR analysis for diagnosing the existence of

the *risk-taking channel*, despite the common observations that these three variables exert influences on each other simultaneously. The lag order of the model is set as 2 based on Schwarz information criterion and the F -statistics for model reduction.

Figure 6. Impulse Response from VAR Analysis



Note: 1. *INT* and *HPG* denote Federal Fund Rates and the growth rate of realized NHPI.

2. Confidence bands are based on the 95% significance level.

Data Source: Federal Reserve, Federal Housing Finance Agency, Duca *et al.* (2011)

Figure 6 includes the impulse responses of each endogenous variable to the three structural shocks. Our main interest lies in whether the LTV ratio responds negatively to a monetary policy shock. In addition, we can see whether the LTV ratio reacts positively to *HPG* as indicated by the results of the regression analysis presented above. The left panel of the bottom row in the same figure is of primary interest to us. It shows that the response

path of the LTV ratio to a monetary policy shock and it is consistent with the hypothesis presented above on the *risk-taking channel*. A positive increase of 100bp in short-term interest rates leads the LTV ratio to decrease by a maximum of 0.5%. This implies that an expansionary monetary policy shock will result in higher the LTV ratio through the *risk-taking channel*. The impulse response function is consistent with the regression results presented above.

The second panel in the bottom row of that figure shows that a positive shock to house prices increases the LTV ratio. The result also confirms the legitimacy of the regression result despite the relatively subdued magnitude of the response of the LTV ratio. As stated previously, lenders are likely to underestimate the risk latent in housing-collateralized lending as housing prices appreciate. Another notable feature of this impulse response analysis is the response of *HPG* to a contractionary monetary policy shock. The first panel in the middle row is consistent with recent findings using a VAR approach (Bjørnland and Jacobsen, 2010; Musso *et al.*, 2010) in that an increase in short-term interest rates induces housing prices to deflate.

4 Developing a DSGE Model

In this section, a DSGE model will be developed to analyze the influences of the *risk-taking channel* on the overall economy. The model features two types of households which are patient households (savers) and impatient households (borrowers). Households supply firms with labor as an input to production and spend their labor income to accumulate residential housing and consume other goods. Savers who are more patient than borrowers save a fraction of their labor income and lend the funds to borrowers facing a borrowing constraint. In return for the funds lent, savers earn interest from borrowers. Firms produce wholesale consumption goods using only labor. Monopolistically competitive retailers buy the intermediate goods from firms and price these goods for sale. However, as in Calvo (1983), only a certain proportion of retailers can adjust retail prices subject to the predetermined probability that a random signal arrives. The restriction on price re-optimization introduces nominal rigidities into the model.

A simplifying assumption is introduced regarding the use of housing. Housing in this economy is solely for residential purposes unlike that in Iacoviello (2005) and Iacoviello and Neri (2010) where it is used for production purposes as well. In these two papers, the production technology comprises housing as an input. This simplification makes the model consistent with the estimation of the LTV ratio equation in Section 3 since data comprising only home mortgages was used for the estimation.¹⁵

¹⁵If data on the LTV ratio of business properties were available, this baseline model can be expanded to include an entrepreneurial sector. We leave this for future research.

4.1 Patient Households

There is a continuum of identical patient households (savers) denoted by P . A representative patient household maximizes a lifetime utility function given as below.

$$E_0 \sum_{t=0}^{\infty} \beta_P^t \left[\ln c_t^P + j \ln h_t^P - \frac{(L_t^P)^\varphi}{\varphi} + \chi \ln \left(\frac{M_t^P}{P_t} \right) \right] \quad (6)$$

Consumption c_t^P , holding of housing h_t^P and real money balances $\frac{M_t^P}{P_t}$ affect the level of utility positively whereas hours worked L_t^P brings disutility to households. β_P refers to the discount factor with $0 < \beta_P < 1$, j and χ denote preference for housing and real money balances respectively, and φ is related to the elasticity of labor supply. The budget constraint faced by patient households when maximizing expected utility is given as follows.

$$c_t^P + q_t(h_t^P - h_{t-1}^P) + s_t^P = w_t^P L_t^P + \frac{R_{t-1} s_{t-1}^P}{\pi_t} + F_t + T_t^P - \Delta \left(\frac{M_t^P}{P_t} \right) \quad (7)$$

where q_t denotes real house prices ($\frac{Q_t}{P_t}$), s_t is real savings, w_t^P is real wages. Patient households consume goods and accumulate housing while saving a certain fraction of the total income which comprises labor income, real interest income $\frac{R_{t-1} s_{t-1}^P}{\pi_t}$, dividends from the retailers (F_t) and transfer from the central bank (T_t).¹⁶ Increments in real money balances are funded by the various sources of total income.

4.2 Impatient Households

The group of impatient households (borrowers) denoted by B , also has unit mass and maximizes the same type of utility function as savers.

$$E_0 \sum_{t=0}^{\infty} \beta_B^t \left[\ln c_t^B + j \ln h_t^B - \frac{(L_t^B)^\varphi}{\varphi} + \chi \ln \left(\frac{M_t^B}{P_t} \right) \right] \quad (8)$$

However, the discount factor of the impatient households is less than that of the patient ones, i.e. $\beta_B < \beta_P$. This condition ensures that the borrowing constraint for the impatient households binds near the steady state with reasonably small shocks.¹⁷ The budget constraint is different from that of savers only in that impatient households are the borrowing

¹⁶ Nominal interest income from lending s_t to borrowers at the previous period is $R_{t-1} s_{t-1}$ where s_{t-1} is nominal savings equal to $P_{t-1} s_{t-1}^P$. Hence nominal interest income from lending the savings can be rewritten as $R_{t-1} P_{t-1} s_{t-1}^P$. Dividing it with overall price level P_t renders real interest income at the current period $(R_{t-1} s_{t-1}^P P_{t-1})/P_t$. Since P_{t-1}/P_t is the reciprocal of the gross inflation rate $\pi_t = P_t/P_{t-1}$, the real interest income at the current period is expressed finally as $(R_{t-1} s_{t-1}^P)/\pi_t$.

¹⁷ Appendix B-1 proves that the borrowing constraint binds at the steady state.

entities and pay interest to savers.

$$c_t^B + q_t(h_t^B - h_{t-1}^B) + \frac{R_{t-1}b_{t-1}^B}{\pi_t} = b_t^B + w_t^B L_t^B + T_t^B - \Delta \left(\frac{M_t^B}{P_t} \right) \quad (9)$$

where b_t refers to the debt owed to patient households.

Additionally and importantly, the impatient households are subject to a borrowing constraint the role of which lies at the heart of propagation and amplification of a monetary policy shock in this model. The impatient households provide the current housing stock as collateral and borrow funds against the expected value of the collateral in the next time period. However, mainly because of the uncertainty latent in future house prices and borrowers' ability to repay the debt, the impatient households are entitled to borrow only a fraction of the total collateral value. To express the constraint,

$$b_t \leq m_t E_t \left(\frac{q_{t+1} h_t^B \pi_{t+1}}{R_t} \right) \quad (10)$$

This borrowing constraint implies the total amount of real debt should be less than a fraction of the discounted expected value of the housing provided as collateral.¹⁸ m_t is the the LTV ratio with $0 < m_t < 1$ and the multiplicative term $m_t E_t (q_{t+1} h_t^B \pi_{t+1} / R_t)$ can be considered as the upper bound of the collateral value which lenders can secure in redeeming a possible default in the following period. Put differently, $(1 - m_t)$ fraction of the collateral value is considered by the lenders as the minimum sum of various costs to be incurred by a default such as the cost for legal proceedings, foreclosing and reselling collateral.

Even though m_t is time-varying in practice and determined by the patient households in the model with the *risk-taking channel* to be presented later, we assume for the moment it is fixed as $\bar{m}$ to provide a benchmark for measuring the effect of the *risk-taking channel*. Henceforth, I will designate the version of the model with the fixed LTV ratio as the *baseline model* and the LTV-endogenized version as the *risk-taking model*.

4.3 Wholesale Goods Firms

The firms produce wholesale goods Y_t by hiring labor from households using the following technology in which labor is a unique input.

$$Y_t = A (L_t^P)^\alpha (L_t^B)^{(1-\alpha)} \quad (11)$$

where A represents total factor productivity and α is the labor income share of patient households. Since the main focus of the analysis is put on the transmission effects of the

¹⁸In nominal terms, $B_t \leq m_t E_t \left(\frac{Q_{t+1} h_t}{R_t} \right)$, and if both sides are divided by P_t , $\frac{B_t}{P_t} \leq m_t E_t \left(\frac{h_t}{R_t} \frac{Q_{t+1}}{P_{t+1}} \frac{P_{t+1}}{P_t} \right)$

shocks to monetary policy and the LTV ratio, we ignore technological shocks and set $A=1$ for the purpose of simplicity. The wholesale firms maximize profit, i.e. revenue of Y_t/X_t less cost of $w_t^P L_t^P + w_t^B L_t^B$, as below.

$$\max_{L_t^P, L_t^B} \frac{Y_t}{X_t} - w_t^P L_t^P - w_t^B L_t^B \quad (12)$$

where X_t is the markup of final goods over wholesale goods defined by a ratio of retail prices to wholesale ones, P_t/P_t^w .

4.4 Retailers

To introduce price rigidities into the model, monopolistic competition and Calvo-type price optimization are assumed at the retail level as in the standard New Keynesian model. A continuum of retailers of mass unity buy wholesale goods from the firms at P_t^w and sell them to consumers at P_t . Aggregate final goods index (Y_t^F) is the integration of demand of each retailer, indexed by i , for intermediate goods as follows.

$$Y_t^F = \left(\int_0^1 Y_t(i)^{\frac{\varepsilon-1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}} \quad (13)$$

where ε represents the elasticity of substitution among differentiated intermediate goods and is over unity ($\varepsilon > 1$). The aggregate price index also derives from integration of the individual price index which the retailers are facing.

$$P_t = \left(\int_0^1 P_t(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}} \quad (14)$$

Given these two aggregate indices, retailers maximize the expected lifetime utility function under a standard type of budget constraint. The maximization yields the following individual demand function for final goods which each retailer faces.

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\varepsilon} Y_t^F \quad (15)$$

Taking the demand function and the wholesale price, P_t^w , as given, each retailer chooses the optimal price $P(i)_t^*$ to maximize the current value of the profit made under the condition that the chosen price remains effective. However, only a fraction, $1-\theta$, of retailers receive random signals during each period and reset the prices while the remaining fraction θ maintains the same price as in the previous period. The optimal price can be obtained

by solving the following problem.

$$\max_{P(i)_t^*} \sum_{k=0}^{\infty} \theta^k E_t \left\{ \Lambda_{t,k} \left(\frac{P_t^*(i)}{P_{t+k}} - \frac{X}{X_{t+k}} \right) Y_{t+k}^*(i) \right\} = 0 \quad (16)$$

where $Y_{t+k}^*(i) = (P_t^*(i)/P_{t+k})^{-\varepsilon} Y_{t+k}$ is the demand for each retailer's differentiated goods and $\Lambda_{t,k} = \beta_P(c_t^P/c_{t+k}^P)$ is the usual stochastic discount factor of the patient household. Without price rigidities, $\theta = 0$, the first order condition of this maximization problem boils down to the condition that the optimal price $P(i)_t^*$ needs to be equalized to the real marginal cost times the desired markup $X = \frac{\varepsilon}{\varepsilon-1}$. Retailers rebate profits $F_t = (1-1/X_t)Y_t$ to patient households. The first order condition of the maximization problem is given as below.

$$P_t^* = X \sum_{k=0}^{\infty} \left[\frac{(\theta\beta)^k E_t \left(\Lambda_{t,k} Y_{t+k}^{*f} P_{t+k}^{-1} \right)}{\sum_{k=0}^{\infty} (\theta\beta)^k E_t \left(\Lambda_{t,k} Y_{t+k}^{*f} P_{t+k}^{-1} \right)} \right] E_t \left(\frac{1}{X_{t+k}^n} \right) \quad (17)$$

Under the Calvo pricing environment, the aggregate price dynamics of the economy is as follows.

$$\pi_t^{1-\varepsilon} = \theta + (1-\theta) \left(\frac{P_t^*}{P_{t-1}} \right)^{1-\varepsilon} \quad (18)$$

where π_t refers to gross inflation $\frac{P_t}{P_{t-1}}$. Linearizing the equation (17) around the steady state and combining it with (18) above yields the standard New Keynesian Phillips Curve (NKPC).¹⁹

4.5 Monetary Policy

In order to close the model, the central bank is assumed to determine nominal policy rates R_t in response to the deviations of inflation and output from the desired level. The specific type of the Taylor rule is given by

$$R_t = R_{t-1}^{r_R} \left(\pi_{t-1}^{1+r_\pi} \left(\frac{Y_{t-1}}{Y} \right)^{r_Y} \frac{1}{\bar{r}} \right)^{1-r_R} e_t^R \quad (19)$$

where $\bar{r}$ and Y denote the steady-state real interest rate and output respectively, and e_t^R is an independently and identically distributed monetary policy shock with zero mean and variance σ_R^2 . The exponent r_R represents the degree of inertia in adjusting policy rates in practice.

¹⁹ A detailed description of the derivation of NKPC is given on pp. 43-49 of Gali (2008).

4.6 Equilibrium

If the necessary conditions for optimization and a set of market clearing conditions are satisfied, the model reaches a unique stationary equilibrium in the absence of shocks to the system.²⁰ The market clearing conditions are for the housing market, $H = h_t^P + h_t^B$, the total output, $Y_t = c_t^P + c_t^B$, and the lending market, $s_t = b_t^B$. The housing stock is assumed to be fixed for simplicity. As stated above, impatient households borrow up to the maximum amount savers are willing to lend. By linearizing the set of first-order conditions and market-clearing ones around the steady state, the baseline model boils down to a system of 14 log-linearized equations as presented in Appendix B-3.

5 Analysis of Monetary Policy Transmission in Baseline Model

5.1 Parameter Values for Calibration

To conduct a qualitative analysis of the monetary policy transmission using the baseline model, I choose specific values for parameters based mainly on Iacoviello and Neri (2010) and related papers with a similar motivation and model structure, for example, Iacoviello (2005), Calza *et al.* (2009) and Gerali *et al.* (2010). The number of parameters to calibrate is 12 and the chosen values of the parameters are listed in Table 3.

The values of the parameters in Table 3 are somewhat different from those in other studies. For examples, Gerali *et al.* (2010) sets the impatient households' discount factor β_B to be 0.98 and Gali (2008) sets the price rigidity parameter θ to be 0.66. However, the differences in these parameter values do not substantially affect the quantitative aspects of the baseline model analysis. Furthermore, the choice of the parameter values specified on Table 3.3 ensures a proper solution to the model. Given the prime role of the borrowing constraint, it is worth elaborating on the level of the long-term average LTV ratio. There have been few statistical sources for calculating the long-term average LTV ratio which can be considered a steady-state value for the parameter $\overline{m}$. As there is no consensus on the level of average $\overline{m}$, researchers have used different values for it. Referring to Table 4 in respect of the U.S., Monacelli (2008) sets the annual average of the LTV ratio as 0.75 for the period 1952-2005, Iacoviello (2005) chooses 0.55, while Iacoviello and Neri (2010) use 0.85. For the Euro area, Calza *et al.* (2009) use 0.7.

In contrast to the literature mentioned above, I used the quarterly LTV data estimated by Duca *et al.* (2011) for the U.S. in the previous section. The average of the quarterly LTV ratio from 1980 Q1 - 2008 Q4 is 0.87 which is close to that in Iacoviello and Neri (2010).

²⁰ Appendix B-2 includes the necessary conditions for each sector.

Table 3. Calibrated Parameters

Parameter	Value	Description
Households		
β_P	0.99	Patient households' discount factor
β_B	0.95	Borrowers' (Impatient households') discount factor
φ	1.01	Labor supply aversion
j	0.12	Weight on housing in households' utility function
α	0.64	Labor income share of patient households
Price Rigidities		
X	1.05	Steady-state gross markup
θ	0.75	Probability of maintaining prices
TFP		
A	1.00	Total Factor Productivity
Monetary Policy		
r_R	0.73	Smoothing parameter of the Taylor rule
r_π	0.27	Inflation coefficient of the Taylor rule
r_Y	0.13	Output gap coefficient of the Taylor rule
LTV ratio		
$\bar{m}$	0.87	LTV ratio

Table 4. Average LTV Ratio for Home Mortgage

Literature	LTV ratio	Period	Country	Data Source
Calza <i>et al.</i> (2009)	0.70 ¹⁾	-	Euro Area	various sources ²⁾
Iacoviello (2005)	0.55	-	U.S.	-
Iacoviello and Neri (2010)	0.85	1973-2006	U.S.	Finance Board's Monthly Survey
Monacelli (2007)	0.75	1952-2005	U.S.	Federal Housing Finance Board

Note: 1) Gerali *et al.* (2010) follows the same value of Calza *et al.*(2009).

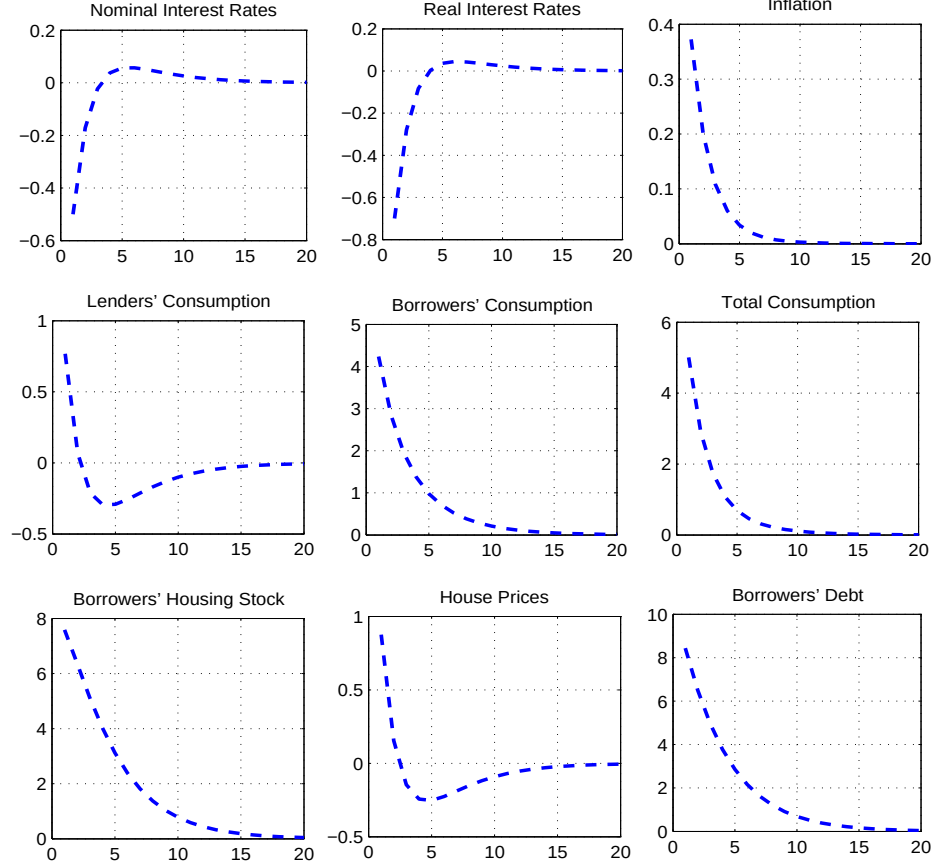
2) For more details, see the Table 1. on pp. 38 in the paper.

5.2 Impulse Response to Monetary Policy Shock

I will focus on the impulse responses of the main variables of interest to a monetary policy shock: consumption, house prices and debt. The main task of this analysis is in

examining if the *risk-taking transmission channel* of monetary policy generates enhanced effects on the paths of these variables. Figure 7, in which the time period is one quarter, plots impulse responses to an expansionary monetary policy shock, i.e. a negative shock to nominal interest rates (R_t). The transmission process starts with a decrease in R_t which

Figure 7. Impulse Responses to a Monetary Policy Shock



Note: The y -axis measures percent deviation from the steady state.

reduces the real interest rate by the Taylor principle. The sufficient condition for satisfying the Taylor principle, as clarified by Bullard and Mitra (2002), is $r_\pi > 1$ in the Taylor rule specified above which implies that real interest rates rise with an increase in the nominal interest rates.

Lower level of real interest rates induce households to expand consumption. In particular, the interest rate channel exerts a stronger influence on the consumption of impatient households than patient ones. The assumption that the discount factor of impatient households is lower than that of patient households implies the former has an incentive to increase current consumption by expanding their borrowing. Another transmission mechanism operates through the changes in house prices caused by an upward pressure on demand in the housing market. As the impatient households spend the additional funds borrowed not only in consuming final goods but also in buying houses, housing prices increase. In

turn, the appreciation in the collateral value increases the maximum amount the impatient households can borrow. Owing to this so-called equity withdrawal effect, households again can consume more than previously. This second channel is an application of the *credit cycle* in Kiyotaki and Moore (1997) to the housing market and analogous to the *financial accelerator mechanism* in Bernanke *et al.* (1999). These two channels, the *interest rate channel* and *house price channel*, compose the transmission mechanism of monetary policy in Iacoviello (2005) and explain why the impatient households' consumption deviates further from the steady state than that of patient households.²¹ ²² These two transmission channels can be illustrated by the following causal flows in which hatted variables denote percent deviations from the steady state.

■ Interest Rate Channel

- Patient Households : $\hat{R}_t \downarrow \longrightarrow \hat{r}r_t \downarrow \longrightarrow \hat{c}_t^P \uparrow$ and $\hat{s}_t^P \downarrow$
- Impatient Households : $\hat{R}_t \downarrow \longrightarrow \hat{r}r_t \downarrow \longrightarrow \hat{b}_t^B \uparrow \longrightarrow \hat{c}_t^B \uparrow$

■ House Price Channel: Equity Withdrawal Effect

- Impatient Households $\hat{R}_t \downarrow \longrightarrow \hat{r}r_t \downarrow \longrightarrow \hat{b}_t^B \uparrow \longrightarrow \hat{q}_t \uparrow \longrightarrow \hat{b}_t^B \uparrow \uparrow \longrightarrow \hat{c}_t^B \uparrow$

To get an idea of the quantitative influence of the equity withdrawal effect, I compare the impulse response of consumption in the baseline model with that from the model in which impatient households cannot borrow with housing as collateral. Figure 8 juxtaposes the impulse responses of consumption to a positive monetary policy shock from the baseline model with that of the model without a borrowing constraint. As shown in the same figure, the impatient households in the economy without equity withdrawal borrow and consume less than they would otherwise. This means that a monetary policy shock is amplified through borrowing against collateral in the baseline model.

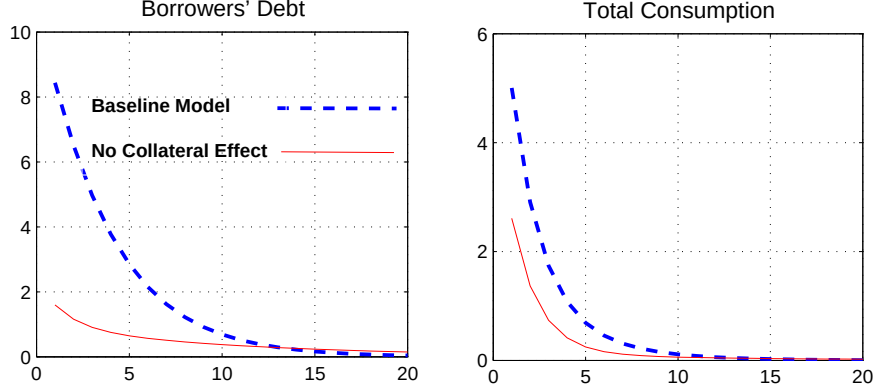
6 Effects of Risk-taking Channel in Mortgage Market

In this section, I will examine whether the *risk-taking channel* in the presence of a positive monetary policy shock generates more volatile paths of the main variables relative to the baseline model. With this in mind, the regression equation for the *risk-taking channel* estimated in Section 3 is incorporated into the baseline model. Endogeneizing the LTV ratio also allows us to examine how a shock to this ratio affects the whole economy.

²¹The term *house price channel* is sometimes termed the *collateral channel*.

²²There is one more channel titled the *debt deflation channel* in Iacoviello(2005).

Figure 8. Comparison of Impulse Responses of Consumption



Note: The y -axis measures percent deviation from the steady state.

6.1 Monetary Policy Shock

Backward-looking LTV Ratio Decision Rule

The main hypothesis of this analysis is that the *risk-taking channel* intensifies the effects of a monetary policy shock in the baseline model since lenders raise their LTV ratio in reaction to the shock. Accordingly, impatient households can borrow more than they would otherwise and increase their consumption and holding of housing stock. By incorporating the benchmark LTV equation into the baseline model, we will examine whether the hypothesis can be supported by the *risk-taking model*. In this model, banks reset the level of the LTV ratio in every period on the basis of the rule expressed in equation (20), that is, based on short-term interest rates and house prices in the previous period.

$$\hat{m}_t = \gamma_1 \hat{m}_{t-1} + \gamma_2 \hat{R}_{t-1} + \gamma_3 \hat{q}_{t-1} + \hat{e}_t \quad (20)$$

where $\hat{m}$, $\hat{R}$ and $\hat{q}$ refer to the deviation of the LTV ratio, interest rates and house prices, respectively, from their steady states. ϵ_t refers to an exogenous shock to the decision process.²³ Low interest rates in the previous period drive them to take more risk for the reasons state previously. To reiterate, these reasons include higher yields from collateralized lending than bonds, underestimation of downside risk to house prices, expectations of robustness in future house prices, and a belief in the ‘too big to fail’ myth.

Table 6 lists the parameter values of the LTV decision rule above. The values are based on the results from the estimation of the regression equation (3).

Figure 9 shows the impulse responses to an unexpected decrease in policy rates by 0.5%p.

²³In the model, banks are assumed to deposit and lend funds at the same interest rate and not to impose any transaction cost. For the purpose of simplification, savers are assumed to act as lenders and banks at once.

Table 5. Parameter Values for Backward-looking LTV Decision Rule

	γ_1	γ_2	γ_3
Value for Calibration	0.7	-3.2	0.3

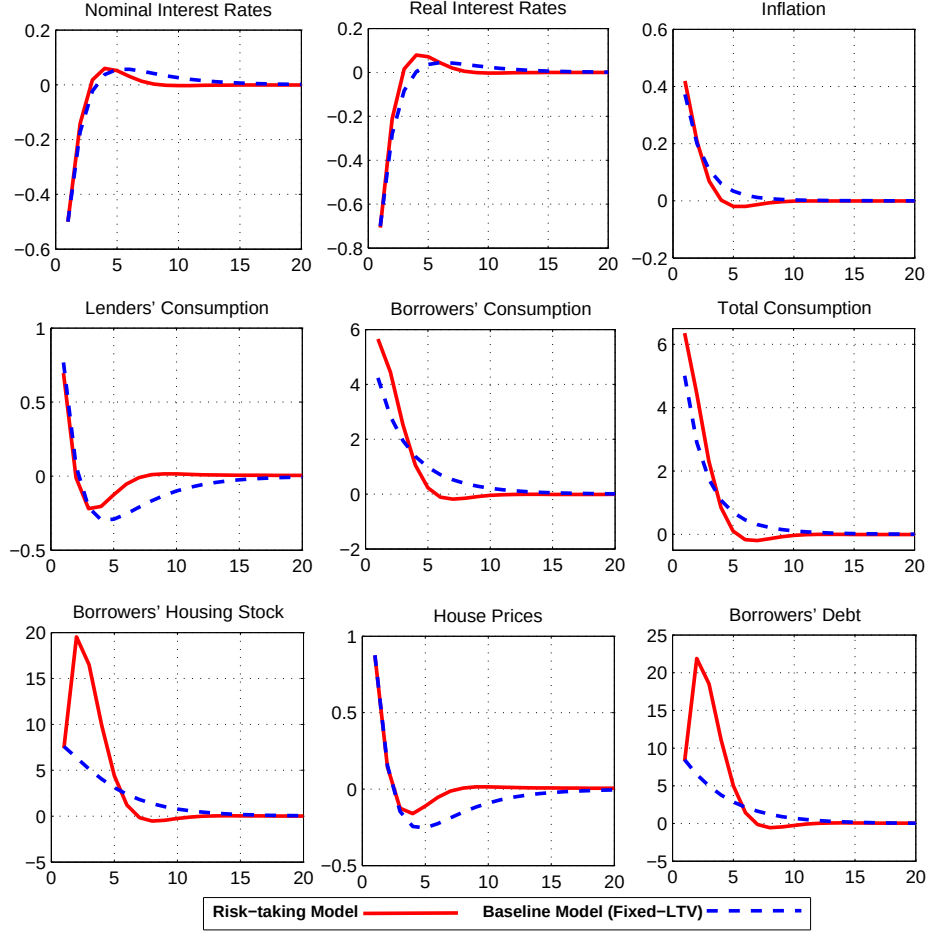
The solid line depicts the results from the *risk-taking model* while the dashed line illustrates the same impulse responses from the baseline model as in Figure 7. It is evident that the traditional *interest rate* and *house price* channels in the *risk-taking model* generate similar positive responses of the variables of interest as the baseline model does. However, the *risk-taking channel* pushes up consumption to a higher level during the first year. Specifically, in the *risk-taking model*, the expansionary monetary policy shock induces consumption to deviate positively by 6.5% from the steady-state whereas it generates an increase of 5.0% in the baseline model. The additional increment in the deviation of consumption results from the increase in borrowers' debt. As suggested by our previous discussion about the *risk-taking channel*, lower interest rates lead lenders to forecast higher house prices in the future and consequently to under-estimate the risk of collateralized lending. Lenders are now willing to provide more funds even if there is no change in the collateral value or income level of borrowers.

The difference in the paths of the economy generated by the baseline model and the *risk-taking model* sheds some light on why central bankers failed to forecast the full effects of the long-lasting accommodative policy on the economy. The two traditional channels, i.e., interest rate and collateral channels, might be taken into account in the estimation of the future path of the economy. However, missing the causal chain between low policy rates and bankers' lending behavior might lead policy makers to underestimate the influence of their decision to maintain low interest rates for a prolonged period in the first half of the last decade.

To continue our discussion, two peculiar features of the impulse responses of house prices and borrowers' debt are noted below.

Firstly, comparing the impulse responses, there exists no difference in the two paths of house prices over the first four quarters. This indicates that the impact of the *risk-taking channel* on consumption results mainly from the decline in policy rates and a subsequent increase in debt rather than the increase in house prices in the first four quarters. In a sense, this is at odds with the hypothesis of the *risk-taking channel*. In the hypothetical economy, lenders adjust their risk-taking attitude by responding to changes not only in policy rates but also in house prices. Fluctuations in house prices send strong signals to mortgage lenders about how risky collateral will be in the future. The *risk-taking model* presented here fails to reflect the causal chain running from realized house prices to lenders' risk-taking attitude in the first four quarters. However, house prices do increase sharply after the first year in the risk taking model. This shows that it takes a while for the risk

Figure 9. Impulse Responses to a Monetary Policy Shock



Note: The y -axis measures percent deviation from the steady state.

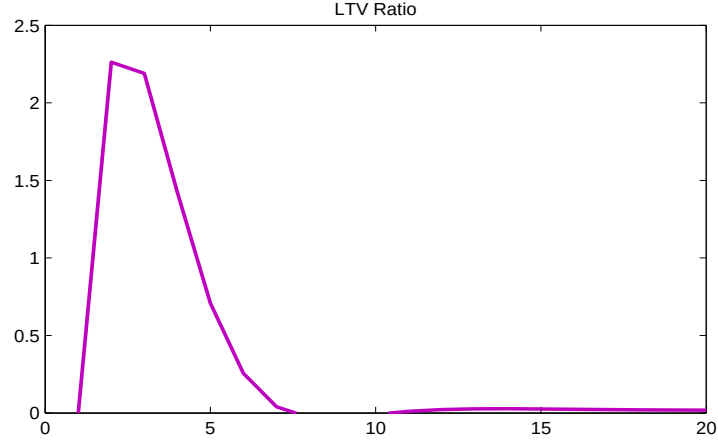
taking channel to have its full impacts; nevertheless eventually house prices do increase much more with the risk taking channel. This is not inconsistent with observations during the recent housing boom.

Secondly, the impulse response of borrowers' debt shows no response in the first period and then a rapid upturn in the second period. This result arises from the assumption that lenders decide their LTV ratios on the basis of interest rates and house prices in the previous quarter. As seen from Figure 10, the impulse response of the ratio reveals an unnatural kink possibly because of the backward-looking behavior of lenders. Under this backward-looking decision rule, the response of borrowers' debt to policy change appears to have a more volatile path than the other economic variables. To overcome these shortcomings, an alternative rule is introduced below.

Forward-looking LTV Ratio Decision Rule

To make the assumption on the behavior of lenders more consistent with reality, a forward-looking decision rule of the LTV ratio is introduced below. Lenders adjust the LTV ratio

Figure 10. Impulse Response of LTV Ratio



Note: The y -axis measures percent deviation from the steady state.

on the basis of the observed level of policy rates and house prices in the current period and also their own expectations of the evolution of these two variables in the next period. Another distinction from the backward-looking rule is the absence of the lagged LTV ratio itself. The omission of the term implies that gradualness in adjusting the LTV ratio is not in the lenders' interest *per se*.

$$\hat{m}_t = \xi_1 \hat{R}_t + \xi_2 \hat{q}_t + \zeta_1 E_t(\hat{R}_{t+1}) + \zeta_2 E_t(\hat{q}_{t+1}) + \hat{e}_t \quad (21)$$

The parameter values in the forward-looking decision rule are obtained by a regression using the same data used in estimating the backward-looking equation. The responsiveness to the contemporary policy rate is lower than that of the backward-looking rule. The forward-looking coefficient, i.e., ζ_1 is still lower. This result makes sense in that lenders put less weight on their own expectation of policy rates because of the uncertainty inherent in forecasting.

Table 6. Parameter Values for Forward-looking LTV Decision Rule

	ξ_1	ξ_2	ζ_1	ζ_2
Value for Calibration	-1.95	0.21	-1.77	0.16

The impulse responses to a shock to monetary policy with a 50bp decrease are illustrated in Figure 11. As anticipated, the two *risk-taking* models with a backward-looking rule and forward-looking rule generate more volatile paths of the economic variables than the baseline model. However, even though the two *risk-taking* models share the common characteristics of the *risk-taking channel*, the overall economy displays enhanced deviations

in the case of the forward-looking rule. In other words, a monetary policy shock is amplified more when lenders adjust their LTV ratios depending on their forecasts for policy rates and house prices rather than on past information on these variables.

House prices, in particular, show a further deviation from the steady state. As lenders expect future policy rates and housing prices will move and they use these expectations when deciding the LTV ratio for every period, they supply more credit to borrowers. If lenders employed only the information in the previous period, their willingness to make loans might be less than it would otherwise. As a result of more mortgage supply, borrowers can consume more housing and non-residential goods. House prices and consumption display more fluctuations. As such, the model employing the forward-looking LTV decision rule overcomes the shortcomings of the model with the backward-looking rule.

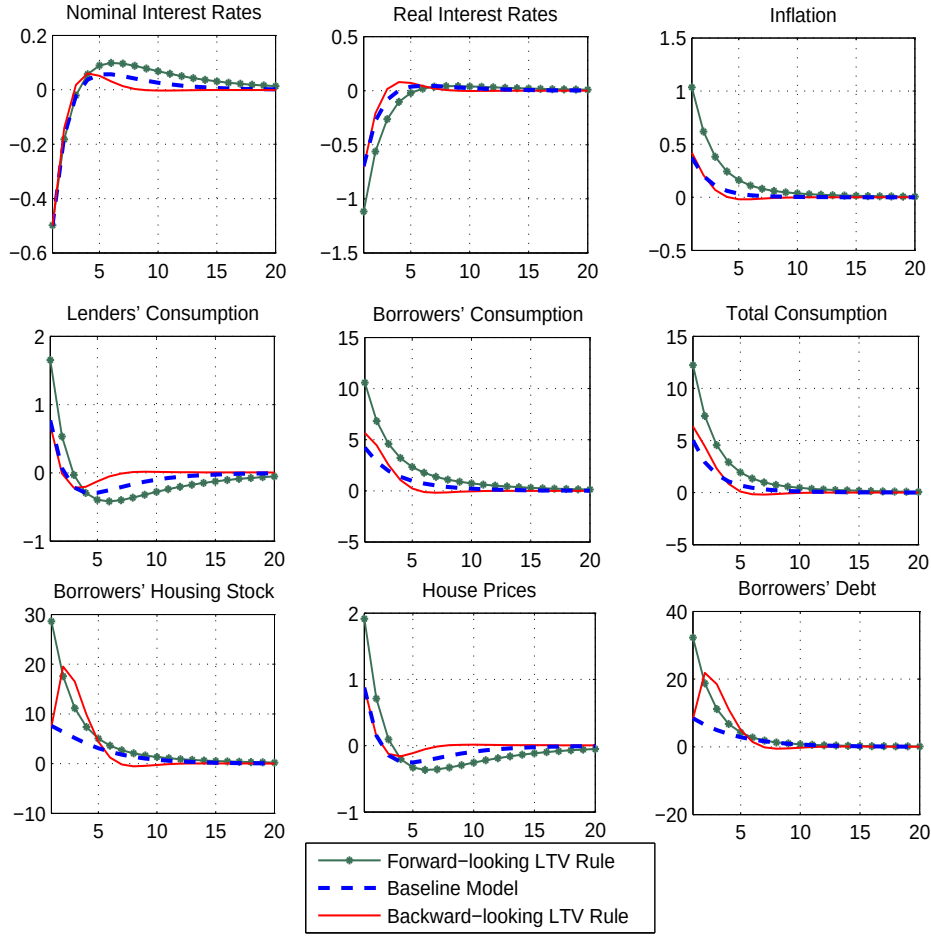
This result provides a forceful insight into the role of the expectations of credit suppliers in the housing market. In retrospect, it is acknowledged that the housing bubble in the run-up to the sub-prime crisis could not have developed only due to the irrational and myopic expectations of housing buyers. One of the main driving forces in the housing market at that time was the infinitely elastic credit supply in response to the demand for loans. Regarding the behavior of bankers, some researchers have raised the possibility that bankers at that time were as irrational as home buyers in forming their expectations of future housing market situation. The impulse responses generated by the model with the forward-looking rule supports this hypothesis. If lenders draw on their own expectations in deciding the LTV ratio instead of using the realized value of policy rates and housing prices, the economy shows a more volatile path than it would otherwise.

6.2 LTV shock

We now turn to what happens to the whole economy if a shock to the LTV ratio decision process arrives using the forward-looking decision rule introduced above. The shock to the decision process can be a wider latitude to adjust downpayment or change the ceiling on the LTV ratio which are caused by changes in banking regulations. In the context of risk-taking attitude of lenders, the shock can be interpreted as changes in the preference for the risk related to housing-collateralized lending which can be caused, for example, by lenders' optimistic expectation about future house prices and economic activities.

Figure 12 shows the impulse responses to a positive shock to the LTV decision process which has the magnitude of one percent deviation from the steady-state the LTV ratio. The positive shock implies that lenders become more aggressive in expanding housing-collateralized loans. After the shock hits the economy, lenders supply more credit given a specific level of housing value and borrowers can increase debt not only for consumption but also for house purchases. As the first panel in the same figure reveals, the shock increases the LTV ratio instantaneously by one percent from the baseline, which implies heightened credit availability and leads to a corresponding increase in borrowers' debt.

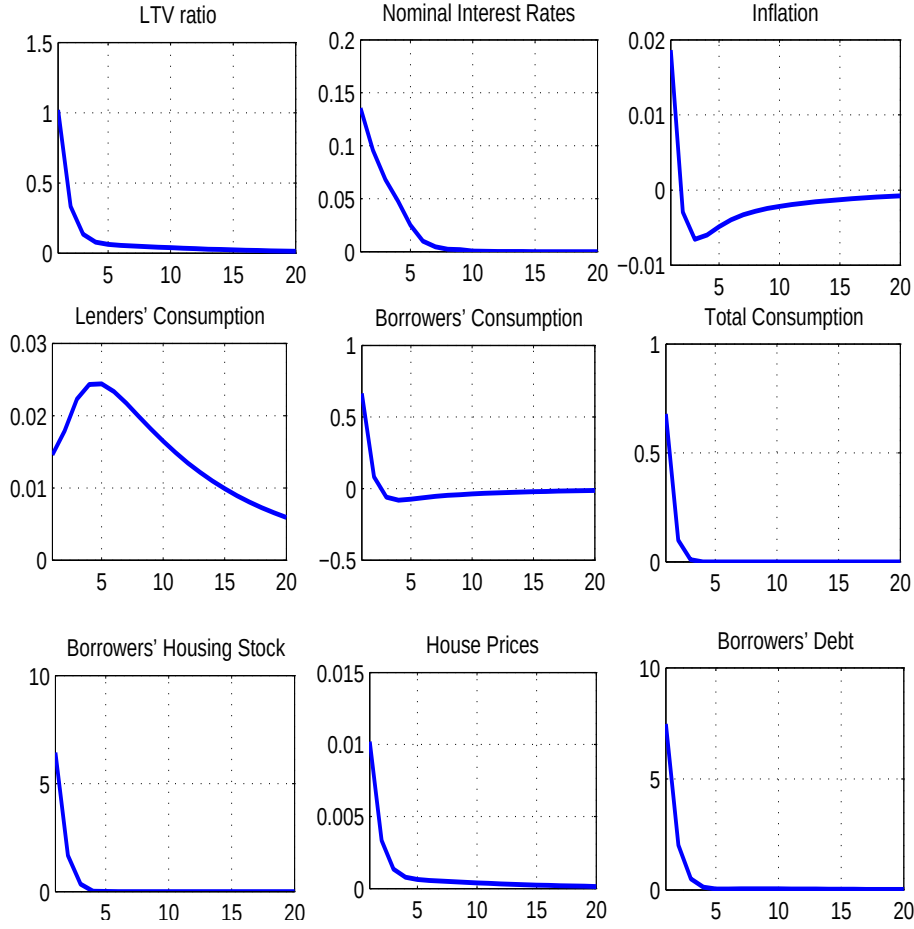
Figure 11. Impulse Responses by Forward-looking LTV Decision Rule



The impulse responses of consumption and house prices are in line with expectation: total consumption increases by 0.8% and house prices rise further 0.05%. The central bank reacts to these output and inflation gaps by increasing policy rates. However, since the gaps are narrow enough to be bridged by a soft response, the magnitude of rate hike is not substantial.

As noted above, an LTV shock exerts only limited influence on the variables compared with a monetary policy shock. The extent to which the variables deviate from the steady state in the presence of an LTV shock is quite smaller than when a monetary policy shock hits the economy. For example, borrowers' consumption deviates by only 0.6% in response to an LTV shock whereas a monetary policy shock causes it to deviate by almost 6% as shown by Figure 11. Similarly, the response of housing prices to an LTV shock is less than with a monetary policy shock; house prices change by only 0.01% with the LTV shock whereas they deviate by 2% in reaction to a monetary shock. These differences can be explained by the difference in the channels through which these two shocks are transmitted. As elaborated above, monetary policy is transmitted through three channels:

Figure 12. Impulse Responses to LTV Shock



Note: The y -axis measures percent deviation from the steady state.

the interest rate channel, house price channel and risk-taking channel. These channels have a long-lasting effect on the economy. On the other hand, an LTV shock directly affects only the amount of lending by patient households to borrowers. Only a 1% deviation of the LTV ratio falls short of exerting strong impact on the behavior of economic variables, which is consistent with the reality.

However, the qualitative property of the simulated paths of consumption and house prices are consistent with what we observed in certain developed countries during the period before the sub-prime crisis. Mortgage lenders enhanced the LTV ratio to 100 percent, in some extreme cases, even up to 120 percent, and consequently existing home owners could withdraw more equity from their houses. The funds borrowed against housing as collateral were spent in purchasing houses and consuming other goods. The increased demand for housing pushed house prices to an unsustainable level. The loop reiterated itself until mortgage related assets, such as mortgage-backed securities (MBS), turned non-performing as a result of the housing market crash and the functioning of the whole banking sector was then crippled.

7 Conclusion

The motivation for the analysis originates from the following queries: (i) Why did central banks and most macroeconomists fail to forecast the rapid economic downturn after the sub-prime crisis? (ii) How did the prolonged period of low interest rates affect banks' mortgage supply? (iii) Does there exist any unidentified relationship between the accommodative monetary policy maintained for a protracted period and the devastating aftermath of the financial crisis?

To answer these questions, a micro-founded model is developed which incorporates the hypothesized *risk-taking channel* of monetary policy into a workhorse DSGE model featuring housing-collateralized lending and a borrowing constraint. In the model, lenders become increasingly aggressive towards risk by increasing the LTV ratio as a reaction to a decrease in policy rates. There are two prominent reasons for lenders assuming more risk. These include *search for yield* and the tendency to under-estimate risk in housing-collateralized lending in the presence of robust growth in collateral value. The specific procedure for setting up a DSGE model which mobilizes the *risk-taking channel* underwent two steps. First, two kinds of empirical analysis were conducted using U.S. data during the period from 1980 to 2007: (i) a set of simple regressions with the LTV ratio as the dependent variable and (ii) a VAR model with short-term interest rates, the LTV ratio, and house prices as endogenous variables. In turn, the estimated regression equation chosen as a benchmark equation merges into the baseline model to make the *risk-taking channel* operative. The overarching aim of the *risk-taking model* is investigating whether the *risk-taking channel* amplifies an expansionary monetary policy shock. Additionally, the model enables us to see how the economy behaves in response to a shock to the LTV decision process.

The analysis of impulse responses generated by the *risk-taking model* confirms the hypothesis that with the *risk-taking channel*, the trajectories of consumption and mortgage debt in the model become more volatile. If the *risk-taking channel* operates, an initial monetary policy shock produces more significant deviations of consumption and borrowers' debt from the steady state relative to the baseline model. In particular, if lenders decide the LTV ratio using their own expectations about the future paths of policy rates and house prices, the *risk-taking channel* turns out to have a greater effect on the economy as a whole.

From the analysis, we can derive several implications for monetary policy implementation and financial regulation. First and foremost, to evaluate accurately the influence of monetary policy decisions on economic and financial activities, we need to take into account the impact generated through the *risk-taking channel* in addition to the impact from the traditional transmission channels. If the effects are not given proper consideration, accommodative monetary policy decisions can instead destabilise the whole economy

since the response of banks and households to the easy stance will be underestimated. Secondly, regulations on the LTV ratio can contribute to the stability of the economy by curbing the aggressive risk-taking behavior at the credit supply side. If the *risk-taking channel* is operating, counter-cyclical regulatory interventions in the lending market (by imposing a lower ceiling on the LTV ratio) can smooth the paths of financial and real economic variables alike.

For future research, two points are worth mentioning. To capture the whole picture of the influence on house prices and the whole economy, we need to consider the *risk-taking channel* on the credit demand side in the mortgage market. Secondly, the process of expectation formation still remain a “black box” in evaluating, both empirically and theoretically, the effects of monetary policy decisions on the housing sector. Hence we need to invest more of our resources in identifying and estimating the effects produced via the expectation channel.

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Appendix 1: Proof of the Borrowing Constraint Binding at Steady State

The Euler equation derived from the patient households' optimization is given by

$$\frac{1}{c_t^P} = \beta_P E_t \left(\frac{R_t}{c_{t+1}^P \pi_{t+1}} \right)$$

and the corresponding steady state is

$$\frac{1}{c^P} = \beta_P \frac{R}{c^P \pi}$$

and as inflation is assumed to be zero at the steady state, namely, $\pi = 1$,

$$R = \frac{1}{\beta_P} \tag{S1}$$

Turning to the Euler equation for the impatient households,

$$\frac{1}{c_t^B} = \beta_B E_t \left(\frac{R_t}{c_{t+1}^B \pi_{t+1}} \right) + \lambda_t R_t$$

and the corresponding steady state is

$$\frac{1}{c^B} = \beta_B \frac{R}{c^B \pi} + \lambda R \tag{S2}$$

Substituting (S1) into (S2) and arranging the terms about λ yields

$$\lambda = \frac{\beta_P - \beta_B}{c} \tag{S3}$$

Since $\beta_P - \beta_B > 0$ by assumption, λ is over zero at the steady state. As the original λ_t measures the increment in the lifetime utility of impatient households accrued by increases in borrowing, there is always room for increasing utility as long as λ is positive. Hence impatient households borrow to the upper limit of the borrowing constraint.

Appendix 2: Necessary Equilibrium Conditions

1. Patient Households as Lenders

$$\frac{1}{c_t^P} = \beta_P E_t \left(\frac{R_t}{c_{t+1}^P \pi_{t+1}} \right) \quad (\text{N1})$$

$$w_t^P = c_t^P (L_t^P)^{\eta-1} \quad (\text{N2})$$

$$\frac{q_t}{c_t^P} = \frac{j}{h_t^P} + \beta_P E_t \left(\frac{q_{t+1}}{c_{t+1}^P} \right) \quad (\text{N3})$$

$$m_t = m_{t-1}^{\rho_m} (R_{t-1}^{\rho_R} q_{t-1}^{\rho_q})^{1-\rho_m} e_t^m \quad (\text{N4})$$

2. Impatient Households

$$\frac{1}{c_t^B} = \beta_B E_t \left(\frac{R_t}{c_{t+1}^B \pi_{t+1}} \right) + \lambda_t R_t \quad (\text{N5})$$

$$w_t^B = c_t^B (L_t^B)^{\eta-1} \quad (\text{N6})$$

$$\frac{q_t}{c_t^B} = \frac{j}{h_t^B} + E_t \left(\beta_B \frac{q_{t+1}}{c_{t+1}^B} + m_t \lambda_t q_{t+1} \pi_{t+1} \right) \quad (\text{N7})$$

$$c_t^B + q_t (h_t^B - h_{t-1}^B) + \frac{R_{t-1} b_{t-1}^B}{\pi_t} = b_t^B + w_t^B L_t^B + T_t - \Delta \left(\frac{M_t^B}{P_t} \right) \quad (\text{N8})$$

$$b_t = m_t E_t \left(\frac{q_{t+1} h_t^B \pi_{t+1}}{R_t} \right) \quad (\text{N9})$$

3. Firms

$$w_t^P = \alpha \frac{Y_t}{X_t L_t^P} \quad (\text{N10})$$

$$w_t^B = (1 - \alpha) \frac{Y_t}{X_t L_t^B} \quad (\text{N11})$$

$$\frac{Y_t}{X_t} = w_t^P L_t^P + w_t^B L_t^B \quad (\text{N12})$$

4. Retailers

$$P_t^* = X \sum_{k=0}^{\infty} \left[\frac{(\theta\beta)^k E_t \left(\Lambda_{tk} Y_{t+k}^{*f} P_{t+k}^{-1} \right)}{\sum_{k=0}^{\infty} (\theta\beta)^k E_t \left(\Lambda_{tk} Y_{t+k}^{*f} P_{t+k}^{-1} \right)} \right] E_t \left(\frac{1}{X_{t+k}^n} \right)$$

$$P_t = \left[\theta P_{t-1}^\varepsilon + (1 - \theta) (P_t^*)^{1-\varepsilon} \right]^{\frac{1}{1-\varepsilon}} \quad (\text{N13})$$

5. Central Bank

$$R_t = [R_{t-1}]^{r_R} \left[\pi_{t-1}^{1+r_\pi} \left(\frac{Y_{t-1}}{Y} \right)^{r_Y} \overline{rr} \right]^{1-r_R} e_t^R \quad (\text{N14})$$

6. Market Clearance

$$c_t^P + c_t^B = Y_t \tag{N17}$$

$$h_t^P + h_t^B = \bar{H} \tag{N18}$$

$$s_t^P = b_t^B \tag{N19}$$

Appendix 3: Log-linearized Conditions

1. Patient Households as Lenders

$$\hat{c}_t^P = E_t \hat{c}_{t+1}^P - \hat{r}_t \quad (\text{L1})$$

$$\hat{q}_t = \beta_P E_t(\hat{q}_{t+1}) + \iota \hat{h}_t^B + \hat{c}_t^P - \beta_P E_t(\hat{c}_{t+1}^P) \quad \text{where } \iota = (1 - \beta_P) \frac{h^B}{h^P} \quad (\text{L2})$$

$$\hat{m}_t = \rho_m \hat{m}_{t-1} + (1 - \rho_m)(\rho_R \hat{R}_{t-1} + \rho_q \hat{q}_{t-1}) + \hat{e}_t^m \quad (\text{L3})$$

2. Impatient Households

$$\begin{aligned} \hat{q}_t = & (1 - m\beta_P) \hat{c}_t^B - \beta_B(1 - m) E_t \hat{c}_{t+1}^B + [\beta_B + m(\beta_P - \beta_B)] E_t \hat{q}_{t+1} \\ & + m(\beta_P - \beta_B) \hat{m}_t - m\beta_P \hat{r}_t - \frac{q}{c^B} \frac{j}{h^B} \hat{h}_t^B \end{aligned} \quad (\text{L4})$$

$$c^B \hat{c}_t^B = -qh^B \Delta \hat{h}_t^B - Rb^B(\hat{R}_{t-1} + \hat{b}_{t-1}^B - \pi_t) + b^B \hat{b}_t^B + (1 - \alpha) \frac{Y}{X} (\hat{Y}_t - \hat{X}_t) \quad (\text{L5})$$

$$\hat{b}_t^B = \hat{m}_t + E_t \hat{q}_{t+1} + \hat{h}_t^B - \hat{r}_t \quad (\text{L6})$$

3. Aggregate Supply

$$\hat{Y}_t = \hat{X}_t + \eta \hat{L}_t^P + \hat{c}_t^P \quad (\text{L7})$$

$$\hat{Y}_t = \hat{X}_t + \eta \hat{L}_t^B + \hat{c}_t^B \quad (\text{L8})$$

$$\hat{Y}_t = \alpha \hat{L}_t^P + (1 - \alpha) \hat{L}_t^B \quad (\text{L9})$$

4. Inflation Dynamics: New Keynesian Phillips Curve

$$\begin{aligned} \hat{\pi}_t = & \beta_P E_t \hat{\pi}_{t+1} - \kappa \hat{X}_t \\ \text{where } \kappa = & \frac{(1 - \theta)(1 - \beta_P \theta)}{\theta} \end{aligned} \quad (\text{L10})$$

5. Central Bank

$$\hat{R}_t = r_R \hat{R}_{t-1} + (1 - r_R) [(1 + r_\pi) \hat{\pi}_{t-1} + r_Y \hat{Y}_{t-1}] + r_R \hat{R}_{t-1} + \hat{e}_t^R \quad (\text{L11})$$

6. Equilibrium in Goods, Housing and Lending Markets

$$\hat{Y}_t = \frac{c^P}{c^P + c^B} \hat{c}_t^P + \frac{c^B}{c^P + c^B} \hat{c}_t^B \quad (\text{L12})$$

$$0 = h^P \hat{h}_t^P + h^B \hat{h}_t^B \quad (\text{L13})$$

$$\hat{s}_t^P = \hat{b}_t^B \quad (\text{L14})$$