Essays on Credit, Asset Prices and Macro-Prudential Policy

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Economics

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Declaration

I hereby declare that the thesis below is my own work and has been generated by me as the result of my own original research.

Luke Buchanan-Hodgman

Abstract

Chapter one of this thesis examines the behaviour of credit volumes, asset prices and output for US data using a dummy-augmented vector autoregression model. The paper contributes to the literature in three ways. Firstly, statistical analysis indicates that from 1985 onward house prices exhibit phase-shift in leading output. Over the same period, data shows that household credit becomes noticeably less volatile relative to output, whereas fluctuations in business debt become more pronounced. Secondly, Granger-Causality tests show that there is significant feedback between house prices and household credit. This result was robust to periods of high and low household debt service costs. Interestingly, changes in interest rates are shown to Granger-Cause changes in house prices and credit volumes only during periods when debt service costs are above the long-run average rate. And third, the magnitude of the responses of credit and asset price variables to variety of shocks are sensitive to whether debt service costs are higher or lower than average. Specifically, when financial obligations are high a shock to the residual in the interest rate equation produces an amplified response in credit and asset price variables.

Chapter two constructs a New-Keynesian DSGE model with multiple credit constrained agents in order to examine whether expectational shocks to the loan-to-value (LTV) ratio

can create cyclical behaviour in output and house prices. The contributions of this paper are threefold. Firstly, when agents anticipate a future loosening of the LTV ratio and this expectation turns out to have been incorrect, house prices, consumption, investment and output all suffer a sharp decline. Secondly, the paper shows that in order to generate downward comovement of output and house prices in response to a frustrated expectational shock to the LTV ratio, agents must be able to post a substantial quantity of the total value of their housing asset as collateral. And thirdly, the ability to post capital as well housing as collateral significantly amplifies the cumulative loss of both output and house prices in the face of a frustrated expectational shock to the LTV ratio.

Chapter three examines the efficacy of two types of macro-prudential policy in an estimated DSGE model with a banking sector. Both in the case of counter-cyclical capital requirements (CCR) and a lean-against-the-wind (LATW) type Taylor Rule, policy is anchored to house price growth. Using a conventional central bank loss function as the metric to gauge the efficacy of macro-prudential policy, the model indicates a reduction in the variation of output of up to 7.38% in the case of a technology shock, and 22.14% in the case of a monetary policy shock when the CCR is the instrument of choice. However, policy in this form exacerbates fluctuations in inflation in the case of technology shock in the region of 4.99%. If the source of the shock is through housing preference, loan-to-value or bank capital, policy in this form unambiguously increases the variance of both output and inflation. If policy takes the form of LATW, the output-inflation trade-off is more pronounced in the case of a technology shock. The improvements in reducing the variance of output and inflation are lessened when LATW is active rather than CCR for a monetary policy shock. The model indicates that any improvement in stabilising output and inflation is significantly offset by a pronounced increase in the variance of credit growth when policy is in the form of CCR.

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For Papa

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Chapter 1

Credit, Asset Prices and Output: what can we infer from the data?

1.1 Introduction

The post-crisis macroeconomic research agenda has been dominated largely by theories that introduce, in a multitude of ways, the financial sector into current orthodox models. If the financial system is considered only as a complex channel through which exogenous shocks are amplified and propagated (Bernanke, Gertler and Gilchrist, 1999), then its importance as a channel to the real economy has until recently been grossly underestimated.[1] However, it is not only the complexity of the channel of financial intermediation that matters when accounting for economic fluctuations: the pro-cyclical nature of a range of financial variables appears *prima facie* to matter also. The criticism of pre-crisis models is directed if not on

[1]Models that utilise amplification and propagation mechanisms, by construction, focus on the channel through which exogenous shocks affect the real economy. This view has been critiqued as it detracts from the possibility that the shock itself could come from within the system rather than without (Hume and Sentance, 2009)

the omission of these features, then at least to their diminished importance in operational models.[2]

The post-crisis inception of, *inter alia*, the international Financial Stability Board (FSB) and UK Financial Policy Committee (FPC) is indicative of the widespread consensus that elements of the financial sector require substantial oversight. However, this would be ill-defined as a synthesis of pre- and post-crisis policy. Indeed, the supposition that we can abstract from the financial sector, and concomitant variables, is largely a modern phenomenon. Smith noted the existence of periods of so-called '*over-trading*'; in which excessive credit creation leads to speculation, only to reverse with a sharp contraction in credit volumes when '*the demand [of creditors] comes before returns'*.[3] J.S.Mill commented that during periods of excessive speculation '*a great extension of credit takes place*'.[4] Similar remarks are echoed by Wicksell, stating that, in the face of higher profits, credit can expand significantly.[5] Adding the caveat that '*[A]s soon as the incentive disappears, the contraction is correspondingly catastrophic.* The use of the word '*catastrophic*' is indicative that Prof. Wicksell was somewhat aware of the quantitative relation between the extent of the speculative credit boom and the welfare loss associated with the subsequent downturn. In the early twentieth century, Irving Fisher developed a theoretical model of booms and depressions; positing that *the dominant factor [in a boom is] over-indebtedness* (Fisher, 1933).

This paper aims to document the statistical lead-lag behaviour, and explore the Granger-

[2]Pre-crisis research tended to be in the tradition of (Woodford, 2003) - i.e., macroeconomic stability was sufficiently achieved through manipulation of the short-term rate. Collateral constraints and other such features capturing macro-financial behaviour - see Kiyotaki and Moore (1997) and Bernanke et al. (1999) - remained largely outside the focus of policy setting institutions.

[3]Smith, A (1776). An Inquiry into the Nature and Causes of the Wealth of Nations. IV.1.16

[4]Mill, J.S (1848) Principles of Political Economy Part II. Chapter XII: Influence of Credit on Prices: III.12.11

[5]Wicksell, K (1936). Interest and Prices. Chapter VI: The Velocity of Circulation of Money. Page 62

Causal relations, between private debt, asset prices and output since the mid-1980's for the U.S. economy.[6] Unlike other studies in this area, broad private debt has been disaggregated in order to examine separately the contributive importance of business and household debt fluctuations in explaining fluctuations in output. Potential feedback between these variables is also examined. If aforementioned financial variables affect one another and output, is this relationship invariant in magnitude during periods of high leverage? More precisely, does household leverage - as measured broadly by the financial obligation ratio for U.S. households[7] - impact the magnitude of the response of variables to shocks? In order to answer these questions a VAR is specified and augmented by a mechanical dummy constructed in order to capture periods when household leverage is at above average levels. If feedback mechanisms exist, and the response of these variables to a variety of shocks differ between periods of high and low leverage, then this has important implications in a state of the world were policy-makers place a not insignificant weight on stabilising macro-financial indicators.

The remaining contents of this paper are laid out as follows. Section 2 describes both the theoretical and empirical literature pertaining to existing research on credit and financial cycles, with a specific focus on the attendant increase in the pro-cyclicality of a number of variables since the financial liberalisation of the mid-1980's. Section 3 details the dataset; accompanied by key data descriptions of a number of debt and asset price variables. In section 4 the methodology is provided. Section 5 concludes. Data codes and empirical results can be found in the appendix at the end of the paper.

[6] The US was chosen due to the availability of data pertaining to financial obligations and disaggregated debt quantities.

[7] The financial obligation ratio (FOR) measures the amount of disposable income being expended through servicing the liabilities of the household. This is calculated by dividing all monies expended on mortgage, consumer credit, rent on tenant-occupied property, auto leases, homeowners' insurance, and property tax by disposable income.

1.2 Related Literature: Theory and Evidence

For over a century, a major topic of debate among economists was how - if at all - finance ought to be explicitly included in economic models. Modigliani and Miller (1958) exposited a passive view of finance. By showing that, under strict assumptions, the way firms are financed is irrelevant to real activity, the authors propounded a view that became the orthodoxy for much of the latter half of the 20$^{\text{th}}$ century. During this period the financial sector in many advanced economies began to account for an increasing share of GDP. This fact, coupled with a new understanding of the problems of informational asymmetries in credit markets (Stiglitz and Weiss, 1981), motivated researchers to propose transmission mechanisms through which behaviour in financial markets and their structures can affect real activity (Bernanke, 1983; Gertler, 1988; Bernanke and Gertler, 1995).

Since the crisis this schism has markedly narrowed, evidenced by the sharp increase in research examining the role finance plays in explaining economic fluctuations. Primarily, this has been undertaken through the medium of three distinct methodological perspectives. First, by examining historical data concerning financial variables and structures, documenting their evolution and importance over a number of historical episodes (Rousseau and Wachtel, 1998; Reinhart and Rogoff, 2009; Schularick and Taylor, 2012; Jorda et al., 2013). Second, by analysing empirically the feedback relationships between financial aggregates and real variables, while also defining and documenting so-called financial cycles in which these variables move contemporaneously (Kaufmann and Valderrama, 2007; Goodhart and Hofmann, 2008; Claessens et al., 2011a; Drehmann et al., 2010). And third, through the explicit inclusion of financial structures in DSGE models[8] (Bernanke et al., 1999; Iacoviello, 2005; Jermann and Quadrini, 2012; Brzoza-Brzezina et al., 2013).

1.2.1 Theory

The relationship between credit and asset prices, and their effect on the real economy, is opaque, with many plausible hypotheses suggesting channels through which these variables affect economic behaviour. Potential reinforcing feedback effects between credit and asset price aggregates have been of particular interest. Kiyotaki and Moore (1997) (KM hereafter) emphasised this relationship, demonstrating how macroeconomic shocks are amplified and propagated through due to collateral constrained firms.[9] Specifically, how a negative shock which affects the price of assets - serving here as both productive inputs *and* collateral - has an impact on the wider economy by reducing funds available to firms. In a similar vein, Bernanke et al. (1999) (BGG hereafter) show that the external finance premium is a decreasing function of borrowers net worth. As net worth is the difference between a firms' assets and liabilities, a negative shock causing a reduction in the value of assets causes an increase in the premium, or equivalently a widening of the spread between raising funds through equity issuance or debt instruments.[10] Therefore, the difference pertains to the price of credit (BGG) on the one hand, and the quantity of credit on the other (KM).

The concept that borrowers increase their stock of credit by borrowing against rising asset values, which itself induces an increase in the price of said assets, was proposed in earlier works. In a stylised model developed by Minsky (1977, 1982, 1986, 1992), the strongly pro-

[8]For an excellent survey of this literature, see Brunnermeier et al. (2012).

[9]For recent research in this vein, see Gerali et al. (2010); Iacoviello and Neri (2010) and Mendicino (2012).

[10]See Christensen et al. (2007); DeGraeve (2008); Christiano et al. (2010) for a modern treatment

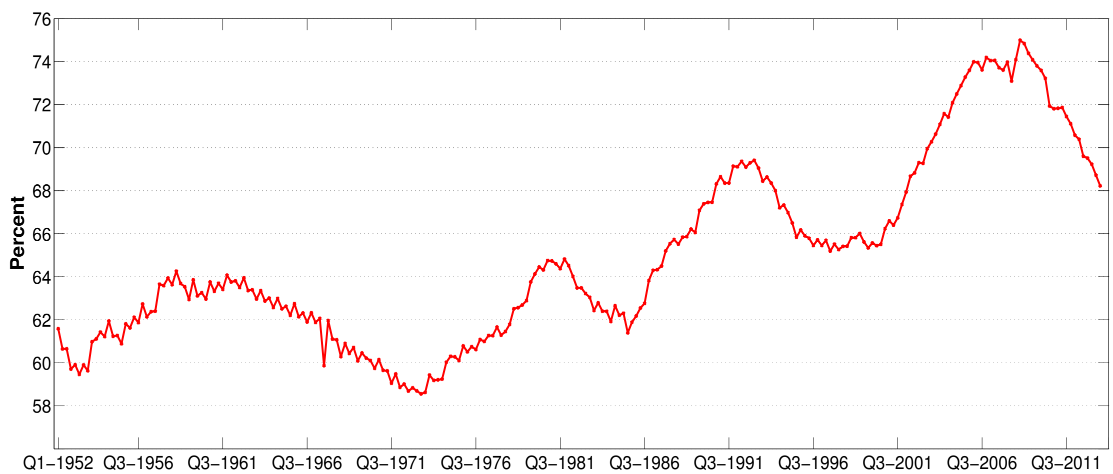
cyclical interplay between asset prices and private lending plays a major role in accounting for economic fluctuations beyond that of an simple mechanical channel. The aptly named Financial Instability Hypothesis (FIH) proposes rather that shocks to real activity are generated by the financial sector. The key difference being that the financial sector is active in the generation of shocks, rather than acting as a passive conduit. Therefore, fluctuations are generated endogenously by highly procyclical credit creation supported by *'waves of euphoria'*. Kindleberger (1978) also viewed the ability of banks' to increase the supply of credit to meet the demand of increasingly optimistic investors as a primary factor in explaining the momentum of crisis periods. However, such models, where they existed, relied on rather unconventional behavioural assumptions and so were summarily discarded as lacking the proper rigour.[11]

Much of the research on the credit channel has focused on the disruptions to the flow of funds to firms. However, the post-2002 economic boom occurred in a period of relatively flat private investment but with a peculiarly high rate of growth in household balance sheet liabilities (Bellofiore et al., 2010). In the years prior to the recent crisis the increase in leverage can almost entirely be attributed to the household sector - the major proportion being mortgage borrowing, as can be seen in Figure 1.1 below. Financial innovation within the area of securitisation in the preceding two decades led to a steadily rising level of household mortgage indebtedness. Mortgage securitisation enabled the transfer of risk from lending

[11] This is best highlighted by Bernanke (1983) - republished in chapter 2 Bernanke (2000) - in which he states "They [*Minsky and Kindleberger*] had argued for the inherent instability of the financial system but in doing so have had to depart from the assumption of rational economic behaviour". For clarity, he follows with "I do not deny the possible importance of irrationality in economic life; however it seems that the best research strategy is to push the rationality postulate as far as it will go". The unorthodox view of speculative behaviour was summarised by Galbraith (1994), who recognised that "They [speculators] are in to *ride the upward wave*; their particular genius [..] will allow them to get out before the speculation runs its course".

institutions to investors with a higher risk appetite, thus boosting the supply of available mortgage funds as banks' were able to remove these from their balance sheets. This began in the 1980's, but became particularly prevalent in the early 2000's when mortgage-related securitisation increased markedly and led to a structural change in the standard model of mortgage lending (Admati and Hellwig, 2013). If lending institutions are able to package and resell mortgage-related securities, thus shifting risk to the purchasers of these new instruments, then the originators will have a much more limited exposure to the concomitant default risk thus relaxing the need sensible for mortgage screening[12] (Keys et al., 2010).

Figure 1.1: Ratio of Mortgage Liabilities to Total Liabilities (Household)



Authors own calculations.[13]

[12]Supporting this proposition, Ben-David (2011) finds that mortgages that remained on the balance sheet of the issuing lending institution faired better than those securitised and moved off balance sheet. For a survey of the informational, risk sharing and screening issues around securitisation of mortgages; see Bair (2012)

[13]Data was sourced from U.S. National Accounts; Flow of Funds; B.101 Balance Sheet of Households and Nonprofit Organizations

1.2.2 Evidence

On the firm side, credit market conditions impact directly on the ability of firms to accumulate capital required to increase future production. However, this does not apply to the household sector where the relaxation of credit conditions, and its subsequent effect on the value of real estate, may or may not have implications for the level of consumption expenditure (Benito et al., 2006). Theoretically, the channels of pass-through between house prices and consumption expenditure are multi-faceted. The wealth effect of an increase in house prices will not translate into an increase in consumptions expenditure if the real values remain constant.[14] It may also be the case that there is no wealth effect, only that extant binding borrowing constraints are loosened by changes to credit availability, the effect of which leads to increasing house prices and consumption contemporaneously (Muellbauer and Murphy, 1997). Another consideration is the competing wealth and income effects of an increase in the price of real estate. Campbell and Cocco (2007) find that there is a significant degree of age heterogeneity in the effect of rising real estate values on the consumption decisions of households. Older consumers have a higher marginal propensity to consume with the increase in the value of housing while the income effect on younger consumers puts downward pressure on their consumption. However, the transmission of house price inflation to consumption expenditure is more likely to be positive in loose credit regimes (Muellbauer and Murphy, 1997).

Due to their supposed importance in affecting real activity, researchers have been actively documenting the empirical characteristics of a number of financial variables. Following in the tradition of Burns and Mitchell (1946), this fruitful avenue of research has led to the tentative defining of credit and financial cycles; as distinct from business cycles. Innovations in securitisation in the mid-80s, coupled with the wider liberalisation of financial markets more recently, has notably increased the pro-cyclicality of a range of financial variables (Adrian and Shin, 2010). If there is

[14] For an interesting discussion of the theoretical underpinnings of the relationship between house prices and consumption expenditure, see Muellbauer (2007)

significant feedback between the financial sector and real economy, then it is important to determine the direction of causality both between financial variables themselves and their respective impact on output. Specifically, can the cyclical component in an individual variable - in this case, aggregate credit - act best as a proxy for the financial sector? Or is it necessary to combine a broad range of credit and asset price aggregates in order to account fully for the dynamic relations at hand?

Credit Cycles

If economists are to examine only one financial variable and its attendant effect on real activity, then credit, it is argued, is by far the best candidate (Borio, 2012). Drehmann et al. (2011) examine the usefulness of the ratio of credit-to-GDP to its long-run trend, finding this variable the strongest leading indicator for financial distress.[15] In a similar vein, Giese et al. (2014) find that, for a 50 year sample, the credit-to-GDP gap provided adequate signals for policy tightening. The authors also remark that an assessment of a similarly computed gap for real estate prices may also provide policy makers with information as to the *quality* of the underlying capital the borrowing has been projected into.

Utilising an extensive dataset encompassing 14 developed nations over a period of 140 years, Schularick and Taylor (2012) provide ample support to this view. The authors find that a boom in lagged total credit over a five year period is indicative of an increased risk of an imminent financial crisis; this becoming even more prominent when the second derivative of credit changes

[15] This is done by applying one-sided HP filter to the credit-to-GDP ratio in order to obtain the trend, then measuring the gap between the trend and the actual value of the ratio at that point in time. The application of the one-sided filter in this instance is necessary, as in order to make policy decisions in real time the policy makers can only use information up to that period. Importantly, the HP smoothing parameter λ is set to 400,000, accounting for the expected duration of the average cycle in said variables and the frequency of observations (Ravn and Uhlig, 2002). A lambda value of $400,000$ performs well in accounting for longer term trends in private debt burdens (Drehmann et al., 2012). This is seconded by the Basel Committee on Banking Supervision (BCBS), 2010, "Guidance for national authorities operating the countercyclical capital buffer". This specification assumes that the cyclical behaviour of this variable occurs at a frequency one fourth of that of the business cycle.

sign. Interestingly, the authors also find that monetary aggregates are *far inferior* to total credit when assessing the likely event of a near term crisis episode. Haldane et al. (2015) document the volatility of credit growth for both US and UK data. Credit is found to be around 200% more volatile than output for both the UK and US data over the medium term, rising to 500% at business cycle frequencies. Importantly, the authors also find the same degree of volatility is present in equity and house prices. The authors use probit regressions to assess the potential predictive power of lagged credit for financial crises. The results indicate that 5-6 year lagged real credit growth was significant in contributing to the likelihood of a financial crisis, with the lags being indicative that this dynamic is a medium term phenomenon.

Inextricably linked to the development of credit aggregates are both lending standards and delinquency rates. Using data for over 50 million individual loan applications, Dell'Ariccia et al. (2008) find that default rates are significantly related to *past* credit growth. The authors go on to state that the boom in credit is in a large part supported by a loosening of lending standards, as measured by increasing loan-to-income ratios, accompanied by decreasing denial rates. Asea and Bloomberg (1998) also find that non-price terms of lending are closely linked to macroeconomic developments. Using a Markov-Switching model, the authors show that during a high(low) unemployment regime the likelihood of loan collateralisation increases(decreases). Therefore, during booms(busts) non-price terms of lending tend to loosen(tighten) thus acting as a further impetus on procyclical credit growth expansions. Indeed, it hardly seems reasonable to claim that the sustained increase in credit quantities during the previous three decades did not lead directly to a deterioration in the quality of credit. This is best observed through the central role played by defaults in the subprime mortgage market in causing the recent financial crisis.

Although important, analysing credit in isolation to the development of asset prices omits key information.[16] Capturing singularly the behaviour of credit with no anchor on the contemporaneous behaviour of asset prices does not yield the best indicator of the financial imbalances and associated dislocations (Drehmann et al., 2010). Indeed, growing evidence leans toward the inclusion of credit aggregates and asset prices - particularly those pertaining to the value of property - when attempting to approximate empirically the financial cycle (Borio, 2012).

Financial Cycles

Monitoring changes in credit volumes in isolation is a suboptimal indicator of future financial distress. Historical data indicates that the combined developments in both the credit and housing markets improve our ability to forecast financial crises (Borio and Lowe, 2002). Defined as the periodic medium-term comovement of broad credit *and* property prices, financial cycles are shown to intensify and draw-out recessions when there is a contemporaneous downturn in each. The appearance of these distinct low frequency financial cycles emerged in the U.S. data at around the time that financial market liberalisation led directly to the loosening of financial constraints.[17] Drehmann et al. (2010) find that financial cycles occur with markedly lower frequencies than business cycles - typically sixteen years - and are highly synchronised with periods of financial distress.[18] The authors found that, given a joint downturn in business and financial cycles, the average loss of real GDP is 1.2% higher than if a business cycle occurs in isolation to a financial cycle; additionally,

[16] There are a number of studies that focus extensively on excess credit growth. For some excellent examples, see Haldane et al. (2015); Jorda et al. (2013); Dell'Ariccia et al. (2012).

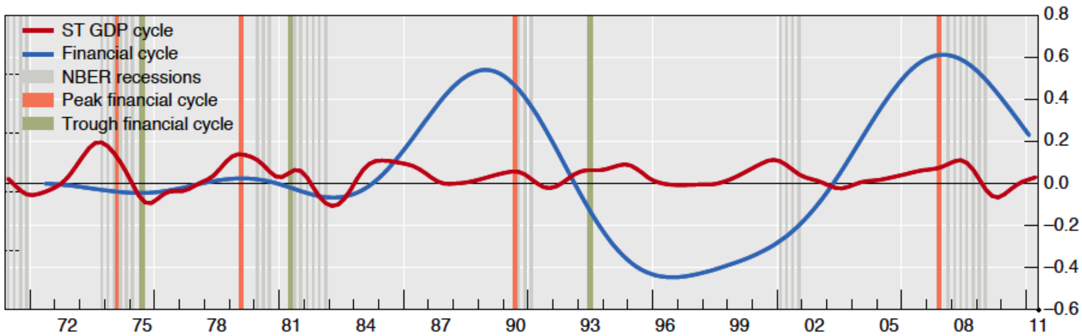
[17] In this sense, the concept of endogenous, self-reinforcing spirals cannot hold in isolation to the policy regime. If this were not the case, then data would exhibit perpetual oscillations in financial variables that were similar in frequency before and after the 1980's. A reasonable *sequitur* is that the associated welfare loss attributable to co-cycle downturns could be stymied by policy aimed at lessening financial excesses during boom periods.

[18] The authors note that equity prices do not fit the characterisation of financial cycles well. They are substantially much more volatile at higher frequencies and comove much less with the other two series. Including them would constitute cycles which evolve in a two-step fashion: one element short term with the other medium term. By extension, many differing definitions of asset price aggregates which contain equity prices perform poorly also.

the authors also found the average loss increases to 1.8% in the post-liberalisation period spanning 1985-2011. Similar findings by Claessens et al. (2011a, b) also bear out these empirical regularities, drawing specific attention to the notable role house prices play in determining the duration and amplitude of recessions.

Figure 1.2 below highlights the appearance of financial cycle in the mid-1980s. The measure of financial cycles was constructed by combining credit aggregates with real estate prices in the U.S., before applying a medium frequency statistical filter. The two post-liberalisation banking crises in the U.S., as defined by Reinhart and Rogoff (2009)[19] occurred both in a tight locality to the peak of a financial cycle. However, of the three stock market crashes post-1985 only two coincided with a financial cycle peak.[20]

Figure 1.2: The Financial and Business Cycles in the U.S.



Note (Source): Orange and green bars indicate peaks and troughs of the financial cycle measured by the combined behaviour of the component series (here; credit, credit-GDP ratio and property prices) using the turning-point method. The blue line traces the financial cycle measured by the average of the medium term cycle in the component series using frequency-based filters. The red line traces the GDP cycle identified by the traditional shorter-term frequency filter used to measure the business cycle
Source: Drehmann et al. (2010)

[19]The banking crisis dates given by Reinhart and Rogoff (2009) are 1984-1991 inclusive, and 2007-2010 inclusive.

[20]The stock market crashes occurred in 1989-1991 inclusive, 2000-2002 inclusive and 2008.

1.3 Data

As noted by Hume and Sentance (2009), the expansion in credit growth in the recent past can be argued to have been US-led.[21] Therefore, and for reasons laid out below, the empirical analysis that follows pertains to U.S. data covering the period 1986Q2-2013Q4, inclusive. The data series used are total real GDP (y_t); total debt outstanding to the household sector (k_t);[22] total debt outstanding to the private non-financial business sector (PNFC) (l_t); average real estate prices (h_t); total value of private non-financial business assets (v_t);[23] loan delinquency rate (dr_t); financial obligation ratio (for_t) and the effective federal funds rate (i_t). Apart from delinquency rates, the financial obligation ratio and federal funds rate, each variable has been converted into real values using the GDP deflator. Excluding the federal funds rate, each variable is seasonally adjusted.[24] Logs have been taken of the level data. To these the HP filter is then applied with smoothing parameter $\lambda = 1,600$, as is common for quarterly data.[25]

Several interesting facts regarding the behaviour of financial variables and aggregate output can be established through analysing the HP filtered data[26] It is clear from the normalised standard

[21]The authors find that, excluding Japan and Germany, a global credit boom - defined statistically at a threshold of one standard deviation in bank lending - in advanced economies was underway in in 2005; this boom itself a continuation of an earlier boom dated 1998-2003. However, for the US the data indicates this boom began in 1995. Thus the authors conclude that the recent credit boom appears *prima facie* to be US-led. See Table 1: Bank Lending Booms 1970-2006.

[22]Total debt outstanding to the household sector refers to the combined debt of all household credit card and mortgage debt.

[23]This is computed by the sum of both financial and non financial assets owned by firms - see Z1 Financial Accounts of the U.S. code: FL102000005.Q.

[24]See Appendix A: Table 1.1

[25]There are alternate methods of converting I(≥1) series' into I(0); such as the first differencing (FD). However, it is a well known result that the FD filter magnifies high-frequency variation in the data while supressing the zero frequency variation. Thus finding such variation post-filtering can be the result of the de-trending technique alone. In contrast, the HP filter supresses low frequency variation while emphasising the variation in the business cycle range, and also does not induce phase shift (Aadland, 2002). That is not to suggest the HP filter does not have its weaknesses. Cogley and Nason (1995b) show that HP filtering difference stationary data can create spurious cycles. Alternately, band-pass filters are available. However, these do not seem to significantly change the properties of business cycles (Cooley and Prescott, 1995) Although there is debate as to which filtering method ought to be applied when studying the properties of business cycles, HP filtering has been and remains industry standard. In order to ensure robustness of the relationships of interest, the results for both methodologies are provided in the Appendix below.

[26]See the Appendix A: Table 1.2 below for normalised standard deviations with respect to output, lead/lag

deviations that each variable varies significantly more than output. This result is consistent for both the full and partial samples. The variation is especially notable for the value of real estate: varying 2.3 that of output for the 1952Q1-2013Q4 full sample range, increasing to 3.1 for the 1985Q1-2013Q4 sub-sample.[27] The variability with respect to output of all variables, bar household debt, increases for the post-liberalisation subsample. This indicates that structural changes in the macro-financial environment have created fertile ground in which the fluctuations of financial variables have become increasingly pronounced. Business debt and the value of business assets most strongly exhibit increased variance, with the standard deviations relative to output increasing by 55% and 53%, respectively. From a simple eyeball test of Figure 1.4, Figure 1.6, Figure 1.8 and Figure 1.10 below, it is clear that for both series' the cyclical variability is becoming increasingly pronounced even within the latter subsample.

All variables are contemporaneously pro-cyclical; as can be observed by the correlation coefficients attributed to these variables in the x column. However, the relative strength of the pro-cyclicality varies widely among variables and across sample periods. The pro-cyclicality of household debt and real estate is stronger for the full sample range, whereas for business debt and assets the converse is true. For the full sample range all variables except real estate, which is coincident with output, exhibit phase-shift in lagging output. This is equally true for the subsample, however it is clear that real estate now exhibits leading phase-shift. This indicates that in all cases bar that of real estate, the variables peak after output. At longer lags, the pro-cyclicality of both business debt and assets is notably higher than that for the full sample. Quantitatively, the fourth quarter lag of business debt is most highly correlated with current output: 80% for the subsample and 62.5% for the full sample. Business assets exhibit a similar tendency: the strongest correlation

relations (i.e., phase-shift), and cross-correlations.

[27]Note that for real estate prices the full sample begins in 1963Q1, not 1952Q1. This is made clear in Table 1.2 in the Appendix. Therefore, the full sample normalised standard deviation could well inherent a degree of upward bias from this significant shortening of the full sample from that of the other variables.

is at the second quarter lag with a value of 83%. Interestingly, past values of business debt appear to be counter-cyclically related to current output. This is robust across samples. These findings tend to indicate that the institutional changes that occurred during the 1980's have promoted not only an increase in the variability of financial variables with respect to output, but have also notably increased the pro-cyclicality of business related debt and assets. Therefore, any model attempting to incorporate the behaviour of private debt and asset prices must specify separately the behaviour of these variables for both the business and household sectors in order to capture these dynamics.

Figure 1.3: Household Debt (k) and Output (1952Q1 - 2013Q4)

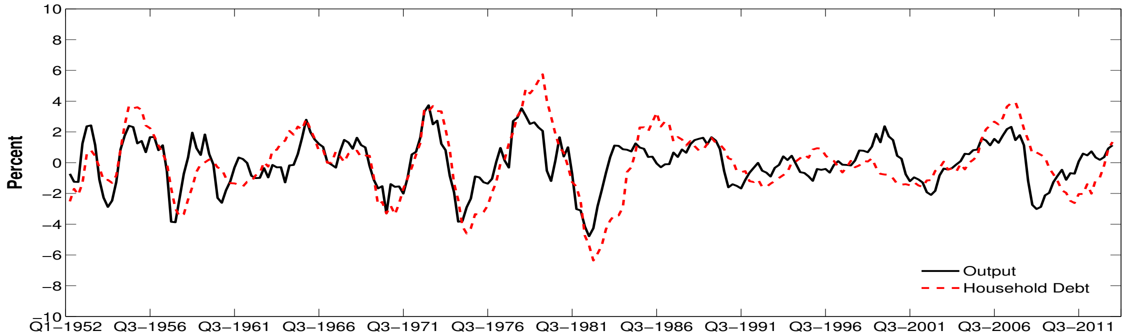


Figure 1.4: Private Business Debt (l) and Output (1952Q1 - 2013Q4)

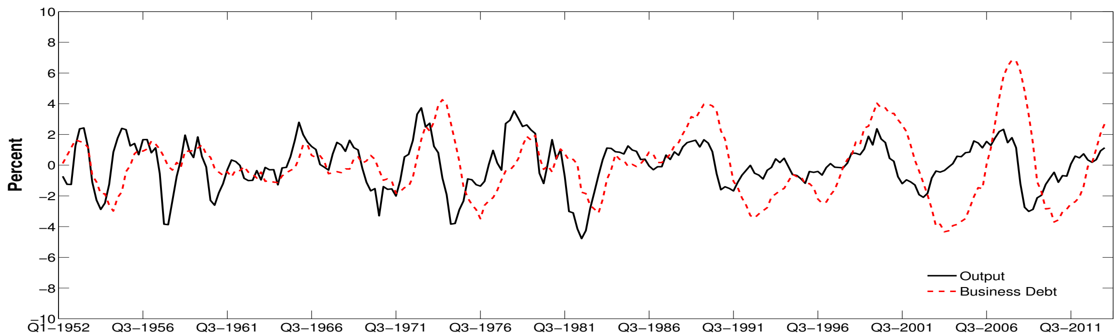


Figure 1.5: Real Estate Prices (h) and Output (1952Q1 - 2013Q4)

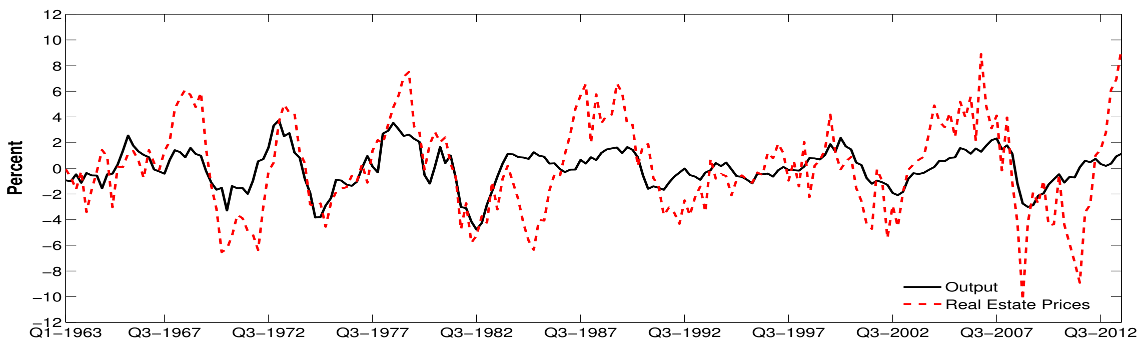


Figure 1.6: Business Assets (v) and Output (1963Q1 - 2013Q4)

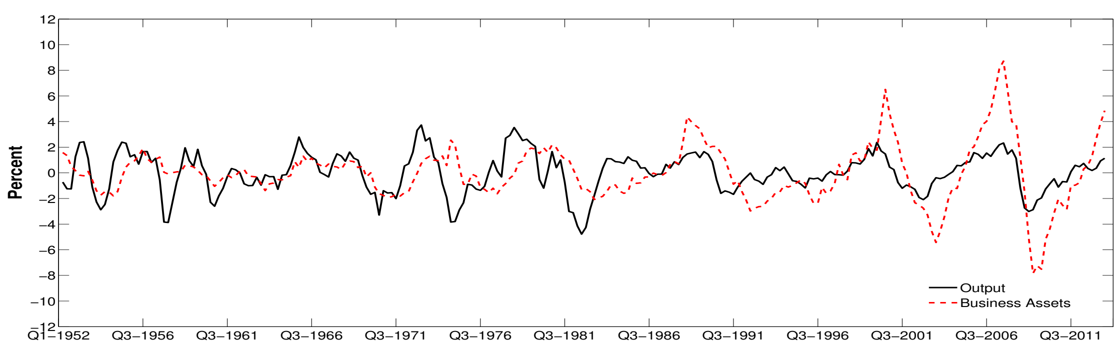


Figure 1.7: Household Debt (k) and Output (1985Q1 - 2013Q4)

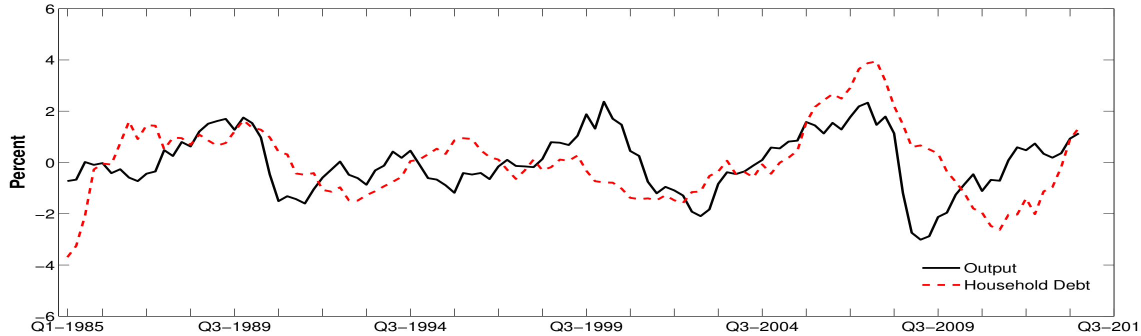


Figure 1.8: Private Business Debt (l) and Output (1985Q1 - 2013Q4)

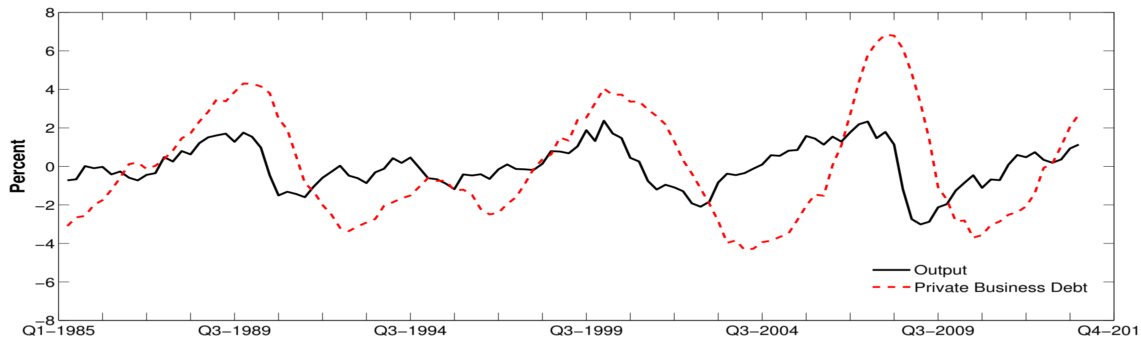


Figure 1.9: Real Estate Prices (h) and Output (1985Q1 - 2013Q4)

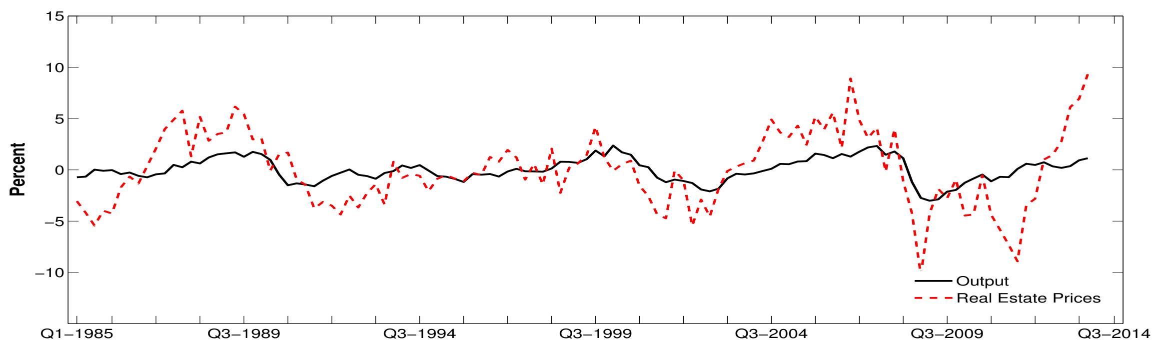
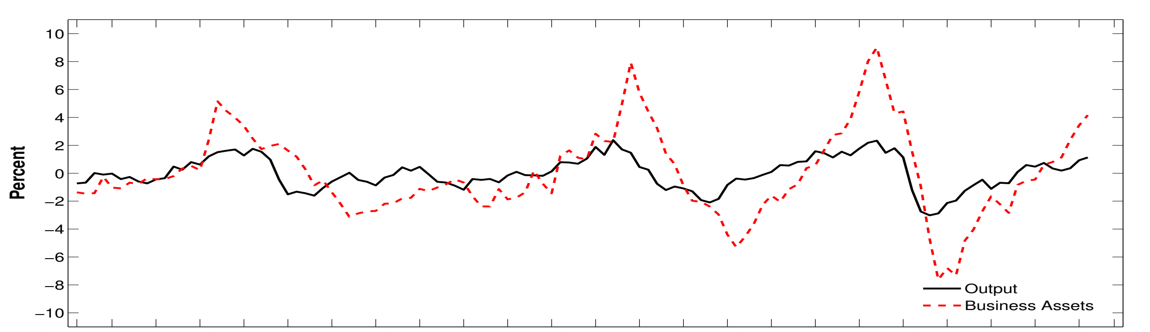


Figure 1.10: Business Assets (v) and Output (1985Q1 - 2013Q4)



1.4 Methodology

A vector autoregression (VAR) is utilised for the analysis.[28] This can be represented in general form thus;

$$x_t = \Pi_1 x_{t-1} + ... + \Pi_k x_{t-k} + \varepsilon_t$$

where x_t is a vector of endogenous variables with coefficient matrices Π_k and ε_t a vector of error terms with the standard $i.i.d$ assumption. The vector of endogenous variables as described above is given as;

$$x_t^{'} = (y_t, k_t, l_t, h_t, v_t, dr_t, for_t, i_t)$$

The methodology followed is standard (Enders, 2003; Lutkepohl, 2005). Firstly, in order to ensure stability of the system the de-trended variables will be tested for stationarity. This requires repeated applications of the Augmented Dickey-Fuller (ADF) test, testing the null hypothesis of a unit root process against the alternate hypothesis that the data series is stationary. Specification of the lag structure will be conducted through use of the lag order selection criteria. As OLS estimation of the VAR assumes well-behaved residual series, normality, heteroscedasticity and autocorrelation will be tested for in turn. The VAR will then be subjected to Block Exogeniety Wald Tests in order to assess statically the significance of the lead-lag relations with respect to output discussed

[28] As shown by Granger and Newbold (1974) and Phillips (1986), where a regression is of the form $y_t = \beta' x_t + u_t$, in which $\{y_t, x_x\} \sim I(1)$, if there exists some value of β' such that $u_t = y_t - \beta' x_t \sim I(0)$ - then OLS estimation is highly likely to produce spurious results. In order to test for the rank of cointegration the Johansen cointegration test (Johansen, 1991) was applied to the system. The Jonansen test is not able to reject the null of no cointegrating relationships over the sample range utilised for the analysis conducted below. This is somewhat expected: ADF tests cannot reject that household credit is an I(2) process. Therefore, a stationary VAR is suitable.

above.[29] The aforementioned test detects whether lagged values of each endogenous variable in the system Granger-Causes changes in other variables. In effect, this tests whether previous values of one variable jointly cannot be rejected as equal to zero when regressed on another variable in the system. The analysis allows for the examination of the interconnectedness of a number of lead-lag relations between financial variables, highlighting where feedback channels may exist between subsets of financial variables.

Impulse response analysis will then be conduced in order to assess the magnitude and direction of the statistically significant relations among variables within the system. Generalised impulse response functions (GIRF) (Koop et al., 1996; Pesaran and Shin, 1998) will be specified due to the common problems associated with identification of short-run fluctuations in unrestricted VAR models.[30]

The model is extended to a dummy-augmented VAR in order to examine whether the magnitude

[29]The test statistic is;

$$(T-3p-1)(log \mid \sum_r \mid -log \mid \sum_u \mid) \sim \chi^2(2p)$$

where T is observations, p is number of lags pertaining to the variable being omitted from the system, $\sum_r$ is the variance-covariance matrix for the restricted system and $\sum_u$ for the unrestricted. See Enders, pp., 282.

[30]Orthogonalised impulse response analysis (OIR) (Sims, 1980) here is problematic. OIR first requires the representation of the reduced form model as a pure moving average (MA) process. The covariance matrix of the error terms (u_t) is given here by $\sum = A^{-1}\Omega A^{'-1}$. IRF utilises the Choleski Decomposition of $\sum = PP^{'}$; P here being a lower triangular matrix. This creates error sequence $u_t^* = P^{-1}u_t$; each being orthogonal to all others. The advantage of this approach is that a shock to an orthogonalised error has no contemporaneous correlation with another. However, P is unique for each ordered grouping of system variables. Therefore, each specific ordering will yield different results, potentially misrepresenting the magnitude and direct of the relations if $\sum$ is not diagonal (Hamilton, 1994). Enders (2003) proposes a number of measures to circumnavigate this potential problem. The author suggests the ordering be first established through previous statistical methods, followed by ordering the remaining variables by increasing correlation ending with the target variable being placed last. When the robust identification of short-run relations is not plausible, it is preferable to employ GIRF in order to examine the dynamic multipliers within the system. GIRFs simply highlight the effect of a typical shock to an endogenous variable, given the estimated covariances of the reduced form shocks (Garratt et al., 2006). Therefore, the impulse responses obtained from this specification are invariant to the ordering of variables in the model. Here, the generalised responses of y_n of a shock to each element of the u_{it} vector is given as;

$$\vartheta(n, \mathbf{y} : u_i) = \Phi_1\vartheta(n-1, \mathbf{y} : u_i) + ... + \Phi_p\vartheta(n-p, \mathbf{y} : u_i) + \vartheta(n, \mathbf{u} : u_i)$$

of the relations between the variables in the system are invariant to periods when household debt service costs are higher than average. As shown in Figure 1.1 above, the build up to the recent financial crisis was categorised by a notable increase in household leverage. When the proportion of household income diverted to servicing debt is relatively high, the impact of a negative shock resulting in lower income or higher interest rates could be amplified. Juselius and Kim (2011) find that losses on real estate loans become highly sensitive to negative shocks when the household financial obligation ratio associated with real estate debt exceeds 10%. Evidence suggests that debt service ratios - calculated as interest and principle repayment on debt divided by income - carry predictive content regarding the size future losses in output during a downturn (Drehmann and Juselius, 2012). The dummy-augmented VAR will be specified thus;

$$x_t = B_{high}(L)x_t(D_t^{high}) + B_{low}(L)x_t(D_t^{low}) + \varepsilon_t$$

where $B(L)$ is defined as the matrix polynomial in the lag operator with an order pre-specified by lag order selection criterion. Analysis of whether the causal relations and impulse responses are sensitive to the degree of leverage in the economy - i.e., when the financial obligation ratio is above its long run mean value - will be undertaken through the creation of a mechanical dummy taking the values $[0, 1]$ when the ratio is below or above its long run mean, respectively. The model is then estimated for each defined dummy. Specifically, as the long-run mean of the financial obligation ratio is 16.8%, the model is estimated for the low and high scenarios in turn - i.e., low $<$ 16.8% and high $\geq$ 16.8%. In the first case, the VAR is estimated with $(D_t^{high}) = 0$, therefore $x_t = B_{low}(L)x_t(D_t^{low}) + \varepsilon_t$. In the second case, the model is estimated with $(D_t^{low}) = 0$, therefore $x_t = B_{high}(L)x_t(D_t^{high}) + \varepsilon_t$. The two models will yield comparative responses with the difference emphasising the alternate reaction to shocks and significance of the causal relations among variables dependent on the proportion of income available to service household debt levels.

In order to reduce the problem arising from too few degrees of freedom the dataset could be extended or a panel VAR estimated. A problem with extending the dataset in the time dimension is due to the structural changes financial markets underwent in the 1980s; their effects observable in the changes to the volatility of many financial time series. Figure 1.7, Figure 1.8, Figure 1.9 and Figure 1.10 above show a simultaneous reduction in output volatility and an increase in the volatility of financial variables occurring during the mid-1980's. The existence of structural breaks during this period is tested through breakpoint regressions on a subset of financial variables. The results lend direct support to this view.[31] Goodhart et al. (2004) argue that the institutional changes led directly to the enhancement of procyclical lending practices, and by extension asset price inflation. However, when private debt and asset price data is analysed for the household and business sectors separately, it is clear that the pro-cyclicality pertains almost entirely to the private business sector, with business debt and assets becoming notably more pro-cyclical during the 1985Q1-2013Q4 subsample.[32] Secondly, the analysis could be undertaken for a group of countries through use of a panel-VAR. Goodhart and Hofmann (2008) utilise such an approach for 17 industrialised nations, analysing the bi-directional linkages between broad money, broad credit and the macroeconomy. Their findings indicate significant multidirectional links, though the impulse responses to shocks are insignificant due to wide confidence intervals. However, there is strong rejection of pooling

[31] In order to text for structural breaks, two methods were used. First, Global Bai-Perron L Breaks vs. None tests were run on a subset of financial variables (Bai and Perron, 1998). The covariance matrix was specified as Newey-West, with a Quadratic-Spectral kernel and Andrews Automatic bandwidth. Errors distributions were allowed to differ across breaks in order to allow for error heterogeneity. Finally, the trimming percentage was specified at 15%, the significance level being 5% and allowing for a maximum of five breaks. The subset of variables tested were total private credit flows to both the business and household sector, real estate prices and business assets. The onset of the recent financial crisis was naturally indicated as a structural break in nearly all variables. Once the sample range was constrained to omit the crisis, each variable indicated significant structural breaks during the 1980's. Apart from business assets - of which the structural break occurred in 1982Q2 - the breaks all occurred between 1987Q3-1990Q2., inclusive. Reaffirming that the breaks are significant, a Chow Breakpoint test was undertaken for each variable at the now-determined breakdates. Results can be found in Appendix 1.B Table 1.5

[32] See Table 1.2 below.

restrictions for the model. The authors also found that for individual countries the results are insignificant or implausible. An additional constraint on extending the analysis to accommodate multiple countries is that only for the U.S. do data exist concerning *all* credit to the non-financial private sector. Therefore, a multi-country study would necessarily require a narrower definition of credit and would for the same reason detract from the primary objective of this paper.

1.5 Empirical Findings

The following results were obtained from the sample range covering 1986Q2-2013Q4, inclusive. This sub-sample was chosen for two reasons. Firstly, in order to focus on the post-liberalisation period; and secondly, due to data constraints. Preliminary statistical tests indicated that all variables were non-stationary. After de-trending each using the HP filter, repeated applications of the Augmented Dickey-Fuller (ADF) test rejected the null of a unit root for each data series.[33] Results for lag order selection indicated mixed lag lengths: for the sequential modified LR test statistic, Final Prediction Error and Akaike information criteria all suggested an order of two whereas both Schwarz and Hannan-Quinn information criteria indicated an order of one. An order of two was chosen as preliminary tests under both lag lengths indicated autocorrelation in the residuals for an order of one but not two.[34] The Jarque-Bera test indicates a significant degree of leptokurtosis and skewness in the residual series'.[35] The null of homoscedasticity is also rejected.[36] These residual tests suggest a cautious reading of the results.

[33]See Appendix 1.B: Table 1.3

[34] See Appendix 1.B: Table 1.4. One note is that specifying the model as a VAR(2) indicated a marginal degree of autocorrelation at the 10% level. This recommends a cautious interpretation of the results

[35]See Appendix 1.B: Table 1.5

[36]See Appendix 1.B: Table 1.6

1.5.1 Plain Vanilla VAR Results

Block Exogeneity Wald Tests indicate a strong degree of Granger-Causality running between many of the variables in the system.[37] Both household and business credit Granger-Cause GDP; significant bi-directional feedback running from GDP to business credit exists also. The causality running from both forms of credit to GDP are robust to the filtering method. The results also indicate significant degree of bi-directional causality running between house prices and household credit. The same applies to business credit and business assets: both exhibit a strong degree bi-directional feedback. Delinquency rates are significant for changes in both household and business credit, with causality running from business credit to delinquency rates being significant at the 1% level also. Interestingly, there is a distinct lack of causality running from interest rates to other variables in the system. Changes in interest rates Granger-Causes business assets only.[38]

Figure 1.11 below yields the generalised impulse responses from the model. The effect of a shock to GDP has a significant positive effect on both business credit and assets; the former returning to zero after 14 quarters, the latter after 11 quarters. A GDP shock has no significant effect on household credit, with only a marginal, but insignificant, positive effect on real estate for 3 quarters. A shock to household credit has a marginally positive effect on GDP, but has a notable positive impact on house prices. The duration of these effects are somewhat short-lived, remaining for only around 3-4 quarters due to the width of the confidence intervals. A shock to house prices induces positive response from GDP, household credit, business credit and assets. The response of

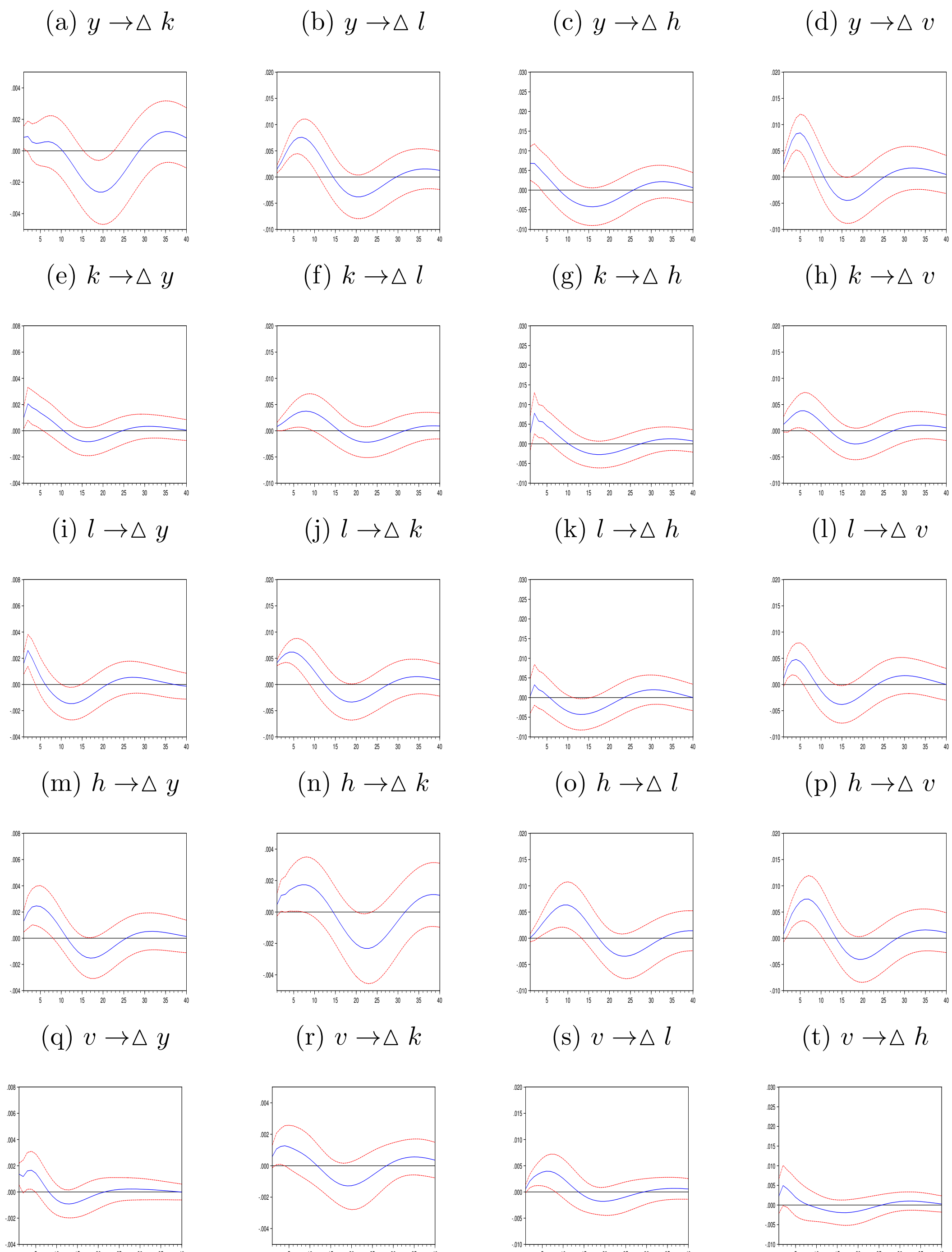
[37] See Appendix 1.B: Table 1.7

[38] A cautious interpretation of the results of the Block Exogeneity Wald Tests is necessary when the data has been treated using the HP filter. As in noted by Hamilton (2017), the HP filter decomposes a time series into a trend and cyclical component which are by construction a function of future realisations: i.e., the filter itself utilises future values of the unfiltered time series in order to produce the trend and cycle components. Therefore, it is unsurprising that bi-directional causality is found between many variable pairs. The robustness of the relations can be found in Tables 1.7 and 1.8 below which provide the results for the Block Exogeneity Wald Tests for variable pairs using the HP filter and also after first differencing the original series.

household credit to a shock to house prices is positive and could be capturing the collateral effect. However, the wide confidence intervals mean that this is not statistically significant. A shock to business assets produces a positive and statistically significant effect on business credit. Again, this could be argued as evidence for as a collateral effect. Delinquency rates react similarly in direction for shocks to both forms of credit and assets classes: falling inittially followed in each case with a significant increase after around 12 quarters. As expected, a shock to delinquency rates induces a significant negative response from both forms of credit.[39] A loose interpretation could be that banks reduce lending volumes after higher than normal loan losses materialise, thus exposing a reduction in underlying credit quality. However, a structural interpretation is not possible in a reduced form model as supply and demand side effects are indistinguishable and the response of credit could instead be driven by a reduction in loan demand. Surprisingly, the response of household and business credit to an interest rate shock is insignificant. Business credit increases marginally in response to a positive shock to interest rates, fading. The response of real estate is negative, but again insignificant. Business assets react positively to a shock to interest rates. Interest rates were Granger-Cause business assets only. The interest rate shock did not induce a statistically significant increase in aggregate delinquency rates, which was due to the width of the confidence intervals.

[39] These impulse responses are available on request.

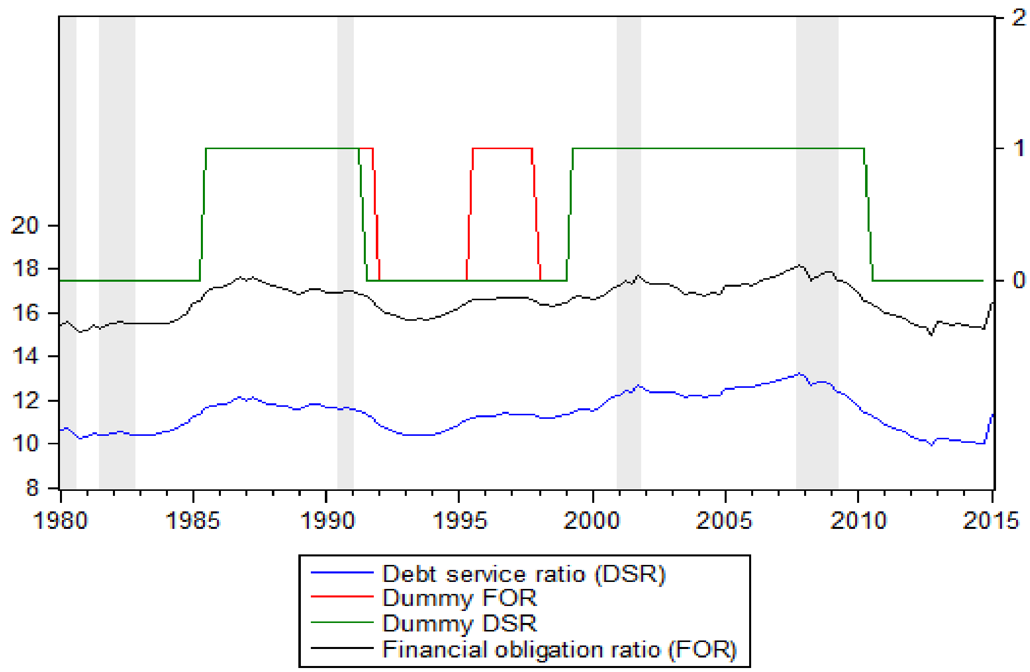
Figure 1.11: Plain Vanilla VAR Impulse Responses (one standard deviation innovation)



1.5.2 Alternate Leverage Regimes

This section will examine the responses of the above model during periods of high and low debt repayment costs out of income. As mentioned above, the model is estimated twice and the results are compared.

Figure 1.12: Financial Obligation Ratio (FOR) and Debt Service Ratio (DSR)



Shaded areas represent NBER dated U.S. recessions.

Figure 1.12 shows time series' for both the financial obligation ratio (FOR hereafter) and debt service ratio (DSR hereafter). The correlation near unity at 0.96. The financial obligation ratio captures a wider variety of household obligations than the debt service ratio. The creation of mechanical dummies representing periods of above average financial obligations encompass in nearly all cases above average debt service requirements also.[40] Therefore, the choice of FOR or DSR in

[40]The data indicate that throughout 1999Q2-2010Q1 inclusive the debt service ratio for households remained above average.

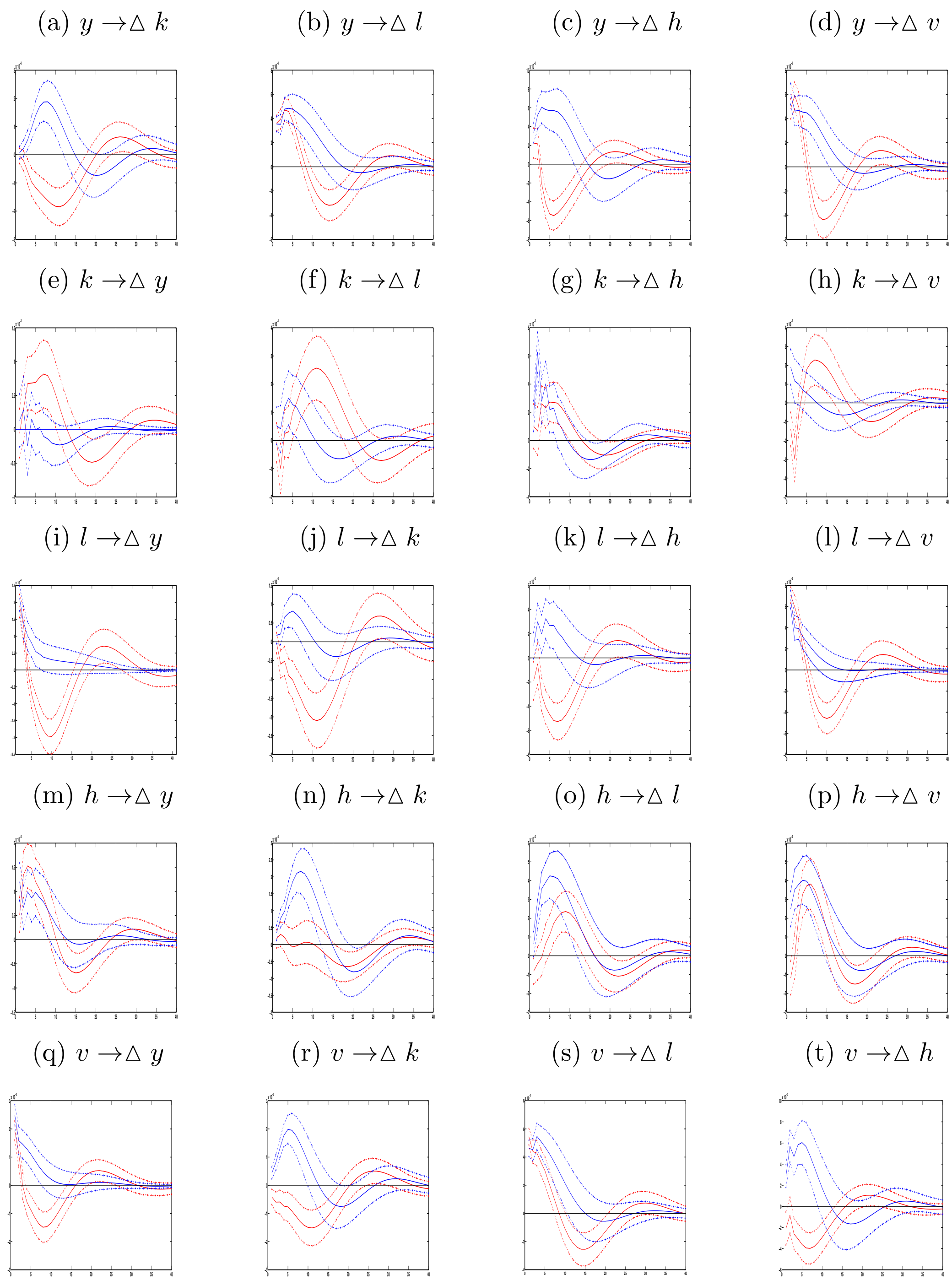
the creation of dummies yields very similar empirical results. As shown by Drehmann and Juselius (2012), high levels of debt service costs carry important information regarding the size of future output losses during economic slumps. This paper contributes to the literature by documenting the lead-lag behaviour of a range of variables and their response to shocks during periods of high and low debt service costs.

The resultant output from each estimation yielded markedly different results. The difference pertains to the order of magnitude of the responses, their significance and, in some cases, their direction. Granger-Causality tests under high/low leverage scenarios indicated that the causal relations which run between variables were peculiarly sensitive to aggregate financial obligations.[41] Changes in GDP now Granger-Cause household credit. Household credit Granger-Causes real estate prices at the 1% significance level. Under the high FOR state, business credit was strongly Granger-Causal for GDP, household credit, real estate and delinquency rates. All relations bar household credit became insignificant in the low FOR state. Results for causality running from delinquency rates to household credit were invariant to the FOR, with both being significant at the 1% level. This indicates that, regardless of obligations, household credit is strongly determined by changes in delinquency rates. This relation did not extend to business credit, which in both cases was not caused by a shock to delinquency rates. The difference between the causal relations for high/low FOR states was most distinct for interest rates. In all cases, bar that of the financial obligation ratio, the high FOR state implied causality running from interest rates to all other variables. In all cases being significant at the 5% level. The converse held true for the low leverage state, with no causality running from interest rates to other variables.

Figure 1.13 provides the magnitude and direction of the shocks under alternate obligation ratios. A shock to GDP in the basic model induced an initial positive and statistically significant response

[41] See Appendix B: B.6

Figure 1.13: High(red)/Low(blue) Leverage Impulse Responses



(a) $y \to \triangle\ k$ (b) $y \to \triangle\ l$ (c) $y \to \triangle\ h$ (d) $y \to \triangle\ v$

(e) $k \to \triangle\ y$ (f) $k \to \triangle\ l$ (g) $k \to \triangle\ h$ (h) $k \to \triangle\ v$

(i) $l \to \triangle\ y$ (j) $l \to \triangle\ k$ (k) $l \to \triangle\ h$ (l) $l \to \triangle\ v$

(m) $h \to \triangle\ y$ (n) $h \to \triangle\ k$ (o) $h \to \triangle\ l$ (p) $h \to \triangle\ v$

(q) $v \to \triangle\ y$ (r) $v \to \triangle\ k$ (s) $v \to \triangle\ l$ (t) $v \to \triangle\ h$

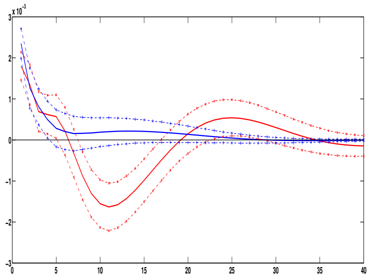
in business credit, business assets, but a marginally significant positive response in house prices. The response of house prices under different obligation ratios are markedly different: a notable negative response in the case of high levels of obligations, and a positive response when the ratio is low. A shock to household credit induces a positive and statistically significant hump-shaped response in GDP, real estate, business assets and credit in the high leverage state. The magnitude of the response in GDP and business credit are greater than that in the low leverage state, with the positive response in GDP being insignificant when obligations are low. When obligations are high, the response of GDP is highly cyclical becoming negative at around the 16th quarter. A shock to business credit induces a positive initial response in GDP and business assets. However, in the case of both business assets and GDP, the response becomes strongly negative after around 5 quarters for the high FOR state, returning to normality after around 20 quarters. In the low FOR state, the negative response is insignificant. The shock has an immediate negative effect on both household credit and real estate in the high leverage state. This is opposite to the response in the low leverage state, where the response is positive and statistically significant. Both variables recover from the shock at around the 20th quarter.

A shock to real estate values induces an initial positive response when financial obligations are low in GDP, business and household credit and business assets. Interestingly, there is a notable increase in household credit expansion for around 10 quarters after the shock relative to the high FOR state where the response is insignificant. This could be interpreted as indicating when existing household obligations are high, an increase in asset values does not induce an expansion in borrowing. The response of GDP becomes negative and statistically significant after the 12th quarter in the high leverage state, but not the low state. The shock to business assets initially produces a positive effect on both GDP and business borrowing. However, in the case of high financial obligations this becomes negative at approximately 5 and 10 quarters, respectively. Most intriguing are responses produced by household credit and house prices. When financial obligations are low, the response is positive and statistically significant in both. However, when financial obligations are high the responses are negative and also statistically significant. This could imply that when bank lending is high, the effect of a shock to business asset values incentivises bank to lend to firms rather than households. Therefore, and due to the strongly significant causality running from household credit to real estate value, house prices fall. Again, any such structural interpretations are only suggestive and cannot be inferred from a reduced-form model.

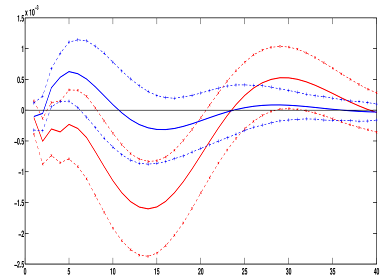
From a simple eye-ball test of the impulses in Figure 1.13, it is clear that where impulse responses become negative, they tend to be statistically significant only in the state of the world defined with above average financial obligations. Shocks when the economy is categorised by high leverage also tend to produce responses much greater in magnitude than their low leverage counterparts. This implies that the reaction among the variables to system shocks are in a large part influenced by the degree of financial obligations on the part of the household. The most notable change in the responses relative to the benchmark model is the degree to which they differ under high and low obligation states after an interest rate shock.

Figure 1.14: High(red)/Low(blue) Leverage Impulse Responses

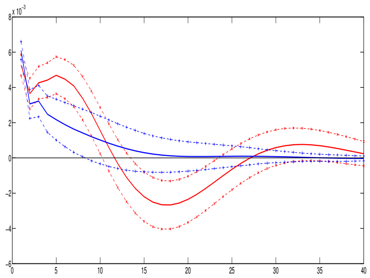
(a) $i \to \triangle\ y$



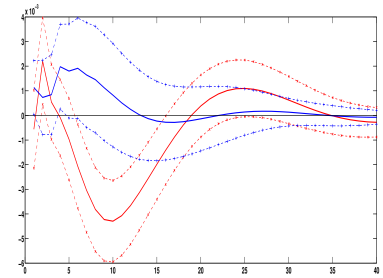
(b) $i \to \triangle\ k$



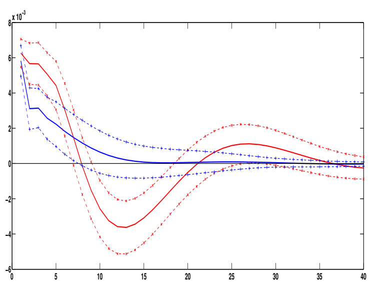
(c) $i \to \triangle\ l$



(d) $i \to \triangle\ h$



(e) $i \to \triangle\ v$



(f) $i \to \triangle\ dr$

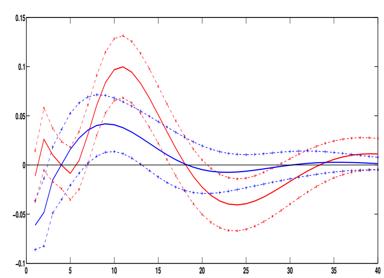


Figure 1.14 above shows the responses after a shock to interest rate equation. In response to an interest rate shock, GDP immediately increase in both FOR regimes. However, when obligations are high GDP continues to decline up until the 12th quarter. The response of household credit is much starker compared across estimations. When obligations are low, household borrowing reacts positively only to quickly dampen out becoming statistically insignificant at around the 5th quarter. However, when obligations are high household credit begins to decline in the 5th quarter and is followed by a more pronounced and significant reduction recovering after approximately 6 years. The response of house prices is of particular interest. After a small initial increase in both states,

house prices show no significant change when obligations are low, whereas they exhibit a strong and highly significant decrease from quarters 5 to 20 when obligations are high. Business assets follow roughly the same pattern. As expected, both regimes show that delinquency rates are strongly affected by interest rates. The duration of the response is common to both, with the magnitude much greater in the high obligations state. The responses become statistically significant after quarter 5. This follows intuitively as on the margin an increase in interest rates pushes up the cost of revolving borrowing in the near term, adding pressure to other borrowing only over medium term horizons.

1.6 Conclusion

This paper contributes to the literature in three ways. First, the lead-lag relations between a range of credit and asset price data are analysed by documenting cross-correlations with output in order to check for evidence of phase-shift. Interestingly, the only variable that exhibits phase-shift in leading output is house prices for the post-liberalisation sub-period from 1985 onward. Also of interest is the change in the normalised standard deviation of credit an asset price data, with all bar household debt varying more with respect to output in the post 1985 sub-sample. Therefore, examining data on aggregate debt omits important information - i.e., the notable increase in the variability of business debt with a contemporaneous, albeit slight, decline in that for household debt. This has implications for the construction of structural models that aim to replicate stylised facts categorising the recent crisis and requires a disaggregation of data concerning debt.

Second, results from the Granger-Causality tests highlighted a number of key relationships and their robustness over periods of high and low financial obligations. There is significant feedback between house prices and household credit, this is robust to both specifications of the VAR. Delinquency rates Granger-Cause household credit under both obligation regimes, but do not do so for business credit. Most interesting of all is the impact of interest rates under the two regimes. When servicing accumulated debt balances are relatively low, the null that interest rates do not impact both forms of debt, business assets and house prices cannot be rejected. However, when a significant proportion of income is diverted to servicing debt the null is strongly rejected in every case.

And third, the magnitude of the responses to a variety of shocks are sensitive to the financial obligations ratio. Specifically, when financial obligations are high a shock to the interest rate equations produces a much stronger response in all variables. Although the model does not allow for a structural interpretation of the shocks, generalised impulse responses do allow us to map the impact of a shock to the residual in the interest rate equation to each system variable.

If policymakers do indeed follow a dual mandate of price and financial stability, and key predictors of future financial distress are credit and asset prices, the tentative conclusions above indicate that monitoring the evolution of debt servicing costs is an important requirement for policy going forward.

1.A Data Appendix

The data series compiled above have been sourced from numerous databases. In what follows, SA and AR stand for seasonally adjusted and annual rates, respectively. Note that each series is in real terms, having been deflated using the implicit price deflator (IPD)

The *U.S. Bureau of Economic Analysis* was used to access data concerning U.S. gross domestic product. The series was chained using the 2009 current-dollar value of the series itself. The series itself is provided in annual rate form, though the data points are quarterly. Note that chaining in this way requires the use of weights, thus the series is not necessarily additive.

Data concerning both total household and total business debt can be located within the *U.S. Financial Accounts of the United States - Flow of Funds* release. Total household debt outstanding can be sourced within Z.1: L.100 row 25 under the heading credit market instruments. This data is estimated from residuals derived from other sectors. Total private non-financial business debt can be located in Z.1: L.101 row 19 under the heading credit market instruments. This data is the sum of estimates for both non-financial non-corporate and corporate business debt. Non-financial corporate can be found directly from the *Quarterly Financial Report* (QFR) - Census Bureau, supplemented by *Internal Revenues Service - Statistics of Income* (IRS/SOI). Non-financial non-corporate data is also sourced from the *Internal Revenues Service - Statistics of Income.*

The data series for real estate prices is located within the *United States Census Bureau.* The data are from *Survey of Construction* (SOC), which is partially funded by the *Department of Housing and Urban Development* (HUD). Within the Census records, the precise data must be located through the section titled Housing, subsection New Housing (Construction). The data series used are contained within the subsection *New Residential Sales* (NRS)*: Quarterly Sales by Price and Financing* - Table Q.6. The precise definition used are for the Average Sales Price for the whole of the United States.[42] It was required to dynamically aggregate the real estate series, which was originally at monthly frequency, to quarterly averages in order to merge with the other series - all of which are also at quarterly frequency. To ensure representative coverage, a multi-stage stratified random sample procedure was used, selecting around 900 building permit offices. This variable was seasonally adjusted following the standard method used by the Fed(see: http://www.federalreserve.gov/releases/z1/Current/z1.pdf. This needs to be done).

Data pertaining to business assets was calculated by the sum of two separate series: non-financial non-corporate business assets and non-financial corporate business assets. Both data series can be sourced at the *U.S. Financial Accounts of the United States - Balance Sheets.* Non-financial non-corporate business assets can be sourced at Z.1: B103 row 1 under the heading Assets. Non-financial corporate business assets can be sourced at Z.1: B102 row 1 under the heading Assets. In both balance sheets, real estate values are calculated at market value and physical capital values are calculated at replacement cost. Interestingly, the percentage of the value of non-financial non-corporate and non-financial corporate business assets held as real estate are 66.04% and 29.58%, respectively.

Loan delinquency rates on all loans and leases for the largest 100 banks in the United States was collected through the *Federal Reserve Statistical Release.* The precise data are calculated using data contained in the quarterly *Federal Financial Institutions Examination Council* (FFIEC) - *Consolidated Reports of Condition and Income* (CRCI) *schedule RC-C.* Delinquency rates for all categories of loans are calculated by the ratio of a bank's delinquent loans relative to the value of loans outstanding for each individual category. Delinquent loans are *'[T]hose past due thirty days or more and still accruing interest.* Potential problems arising from smaller banks' differing definitions of loan categories are circumvented by using schedule RC-K, allowing a consistent def-

[42]Note that this data series is solely capturing residential sales, thus commercial real estate is not being double counted through the data pertaining to business assets.

inition delinquency rates. For more information, see *Charge-Off and Delinquency Rates on Loans and Leases at Commercial Banks - Method of Calculation.*

The Financial Obligations Ratio (FOR) is a measure of the proportion of income flows directed toward meeting outstanding debt obligations. There are a number of repayment obligations contained in this measure: mortgage, consumer credit, tenant-occupied property, auto-lease, homeowners' insurance and property tax repayments. Due to the diversity of variables that are included in the calculation of the ratio, there are a number of individual sources. For the disposable income element, the *National Income and Product Accounts* (NIPA) are used. Data concerning tenant-occupied property, auto-lease, homeowners' insurance and property tax can also be sourced in NIPA. Revolving debt data is sourced from the *Senior Loan Officer Opinion Survey.* Data concerning mortgage and consumer debt can be located in the *Financial Accounts of the U.S. - Z.1*, and *Federal Reserve - Consumer Credit - G.19*, respectively.

Data on the Federal Funds Effective rate was collected from the *Federal Reserve Bank of New York.* The exact source is from the *Federal Reserve Statistical Release* - H.15 (519) *Selected Interest Rates.* The data was converted into a three-month average.

Table 1.1: Data Details and Codes

	Data Series	Main Database	Code	Details
y	Real GDP	Bureau of Economic Analysis	A191RX1	Chained (2009), seasonally adjusted (SA) and represented in annual rates (AR).The series starts in 1947Q1 and is active. All observations are USD.
k	Household debt outstanding	Financial Accounts of the U.S. - Flow of Funds	Z.1: L.100	The original data is in billions (USD) and had not been SA nor inputted in terms of AR. This was corrected prior to analysis.
l	Private non-financial business debt outstanding	Financial Accounts of the U.S. - Flow of Funds	Z.1: L.101	The original data is in billions (USD) and had not been SA nor inputted in terms of AR. This was corrected prior to analysis. The data concerning business debt has aggregated data for both private non-corporate (L.103) and corporate (L.102) business debt.
h	Real estate prices	U.S. Census	see SOC	The NRS data within the SOC pertain to privately-owned single family and multifamily housing units.
v	Total business assets	Financial Accounts of the U.S. - Balance Sheets	Z.1: B.102/3	The sum of B.102 row 1 and B.103 row 1 yield the figure for total business assets.
dr	Delinquency rates on all loans for 100 largest U.S. banks	Federal Reserve Statistical Release	CRCI: RC-C	Delinquency rates on all loans for the 100 largest banks. Data have been SA.
for	Financial Obligation Ratio	Federal Reserve Statistical Release	N/A	The Financial Obligation ratio is SA. As the variable is a ratio, revisions are frequent as the estimations of each individual data series used in its construction occur regularly.
i	Federal Funds Effective	Federal Reserve Statistical Release	H.15 (519)	The effective rate is computed daily, and is a weighted average of rates on brokered trades. 3 month average.

Table 1.2: Cyclical Behaviour of Key Variables: Deviations from Trend, 1952Q1-2013Q4 and 1985Q1-2013Q4

Variable	*SD%*	**Cross-Correlations of Output with (1952Q1-2013Q4)**								
	σ_y/σ_x	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)
GDP	1	0.1340	0.3590	0.6650	0.8490	1	0.8490	0.6650	0.3590	0.1340
Business Debt	1.3701	-0.3774	-0.2617	-0.1113	0.0763	0.2690	0.4289	0.5443	0.6126	0.6250
Household Debt	1.3475	0.0618	0.2045	0.3736	0.5378	0.6651	0.7114	0.6878	0.6035	0.4860
Real Estate	2.3278	0.1703	0.3178	0.4688	0.5826	0.6264	0.5995	0.5169	0.4231	0.3158
Business Assets	1.4259	-0.0860	0.0488	0.1776	0.3125	0.4407	0.5281	0.5653	0.5570	0.5001
		Cross-Correlations of Output with (1985Q1-2013Q4)								
	σ_y/σ_x	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)
GDP	1	0.3480	0.5310	0.7300	0.8900	1	0.8900	0.7300	0.5310	0.3480
Business Debt	2.4626	-0.3748	-0.2213	-0.0468	0.1454	0.3386	0.5044	0.6436	0.7503	0.8044
Household Debt	1.2346	0.0573	0.1539	0.2479	0.3481	0.4193	0.4591	0.4803	0.4984	0.5045
Real Estate	3.1405	0.3752	0.4633	0.5377	0.5778	0.5696	0.4875	0.3758	0.3410	0.2598
Business Assets	2.6820	0.0781	0.2646	0.4373	0.5933	0.7367	0.8155	0.8304	0.7851	0.6904

All variables have been deflated using the implicit price deflator (IPD). Standard deviations have been normalised for GDP. Data pertaining to real estate values begins in 1963Q1 rather than 1952Q1. See Data Appendix for definitions.

1.B Empirical Appendix

Table 1.3: ADF Tests

Variable	**t-stat**	**Prob**	I(d)	**Variable**	**t-stat**	**Prob**	I(d)
$log(y_t)$	-1.61	0.4741	I(1)	$HP(log(y_t))$	-7.01	**0.0000***	I(0)
$log(k_t)$	-1.58	0.4889	I(2)	$HP(log(k_t))$	-6.28	**0.0000***	I(0)
$log(l_t)$	-0.25	0.9271	I(1)	$HP(log(l_t))$	-6.87	**0.0000***	I(0)
$log(h_t)$	-1.46	0.5476	I(1)	$HP(log(h_t))$	-4.82	**0.0001***	I(0)
$log(v_t)$	-0.26	0.9255	I(1)	$HP(log(v_t))$	-6.48	**0.0000***	I(0)
dr_t	-2.13	0.2308	I(1)	$HP(dr_t)$	-3.50	**0.0095***	I(0)
for_t	-2.16	0.2193	I(1)	$HP(for_t)$	-3.88	**0.0028***	I(0)
i_t	-1.52	0.5196	I(1)	$HP((i_t))$	-7.53	**0.0000***	I(0)

Table 1.4: VAR Lag Order Selection Criteria

HP Filtered Data						
Lag	LogL	LR	FPE	AIC	SC	HQ
0	1309.867	NA	7.25e-12	-23.6703	-23.4739	-23.5906
1	2081.198	1416.444	1.89e-26	-36.53087	**-34.76329***	**-35.81393***
2**	2154.484	**123.9191***	**1.62e-26***	**-36.69970***	-33.36093	-35.34548
3	2206.237	79.98184	2.12e-26	-36.47703	-31.56706	-34.48552
4	2256.881	70.90206	2.95e-26	-36.23420	-29.75305	-33.60541
5	2318.174	76.89552	3.60e-26	-36.18499	-28.13265	-32.91892
6	2371.316	58.93850	5.55e-26	-35.98756	-26.36403	-32.108420
FD Filtered Data						
Lag	LogL	LR	FPE	AIC	SC	HQ
0	1548.655	NA	7.30e-23	-28.26890	-28.07137	-28.18880
1	1948.713	734.0507	1.54e-25	-34.43510	**-32.65733***	**-33.71415***
2	2016.878	116.3743	**1.45e-25***	**-34.51152***	-31.15351	-33.14973
3	2061.291	68.45225	2.17e-25	-34.15212	-29.21387	-32.14948
4**	2117.827	**86.00477***	2.73e-25	-34.01518	-27.49668	-31.37169
5	2165.718	59.75405	4.27e-25	-33.71960	-25.62087	-30.43527
6	2232.129	73.11260	5.21e-25	-33.76383	-24.08486	-29.83866

* indicates lag order selection under the relevant criterion; ** chosen lag.

Table 1.5: Bai-Perron Global L. breaks vs. none, and Chow Tests

Variables	**Breakdate**	**Bai-Perron**		**Chow**	
		Scaled F-stat	Cr.V	F-stat	Prob.
Business credit	**1989Q1***	16.20	8.88**	9.02	0.002*
Household credit	**1990Q2***	23.03	5.96	3.00	0.049*
Real estate	**1987Q3***	10.38	8.88**	5.90	0.003*
Business assets	**1982Q2***	21.26	8.88**	7.67	0.007*

*Significant at the 0.05 level. ** Bai-Perron critical values (Econometric Journal, 2003)

Table 1.6: VAR Residual Tests

	FD Filtered Data		**HP Filtered Data**	
Autocorrelation - $H0$: no autocorrelation at lag n				
Lag	LM-Stat	Prob	LM-Stat	Prob
1	63.24706	0.5031	80.30406	0.0820
2	78.10805	0.1106	77.39210	0.1214
3	67.39976	0.3617	61.40802	0.5687
4	68.39177	0.3306	63.55574	0.4922
5	76.09706	0.1431	64.51313	0.4585
6	54.10896	0.8062	63.05311	0.5100
7	59.99723	0.6187	63.21338	0.5043
8	56.96222	0.7214	67.71325	0.3517
9	57.58926	0.7010	50.90312	0.8825
10	66.75709	0.3825	60.19605	0.6117
Normality - $H0$: residuals are multivariate normal				
	Jarque-B	Prob	Jarque-B	Prob
Joint Test	475.9668	0.000	706.1315	0.000
Heteroscedasticity - $H0$: residuals are homoscedastic				
	Chi-sq	Prob	Chi-sq	Prob
Joint Test	2372.8	0.150	1392.1	0.000

Table 1.7: Robustness of Block Exogeneity Wald Test Granger-Causal relations to filtering methods: First Difference (FD) and Hodrick-Prescott (HP)

Causality	**Null**	**FD data**		**HP data**	
		Chi-sq	Prob.	Chi-sq	Prob.
$y \to l$	$H_1 : y \nrightarrow l$	5.63	0.22	4.84	**0.08***
$y \to v$	$H_2 : y \nrightarrow v$	2.32	0.67	7.81	**0.02****
$k \to y$ ‡	$H_3 : k \nrightarrow y$	8.50	**0.07***	5.14	**0.07***
$k \to h$	$H_4 : k \nrightarrow h$	7.16	0.1273	7.85	**0.01****
$k \to for$	$H_5 : k \nrightarrow for$	8.48	**0.07***	3.34	0.18
$l \to y$ ‡	$H_6 : l \nrightarrow y$	13.2	**0.01****	11.2	**0.00*****
$l \to k$	$H_7 : l \nrightarrow k$	9.77	**0.04****	0.84	0.65
$l \to v$ ‡	$H_8 : l \nrightarrow v$	6.40	**0.04****	9.76	**0.04****
$l \to dr$ ‡	$H_9 : l \nrightarrow dr$	22.4	**0.00*****	21.8	**0.00*****
$h \to k$	$H_{10} : h \nrightarrow k$	7.16	0.12	7.85	**0.01****
$h \to dr$	$H_{11} : h \nrightarrow dr$	6.24	0.18	5.87	**0.05***
$h \to i$	$H_{12} : h \nrightarrow i$	5.11	0.27	9.58	**0.00*****
$h \to v$	$H_{13} : h \nrightarrow v$	9.31	**0.05***	3.12	0.21
$v \to l$	$H_{14} : v \nrightarrow l$	7.29	0.12	7.67	**0.02****
$v \to i$	$H_{15} : v \nrightarrow i$	4.82	0.30	6.78	**0.03****
$dr \to k$	$H_{16} : dr \nrightarrow k$	2.36	0.66	10.9	**0.00*****
$dr \to l$	$H_{17} : dr \nrightarrow l$	5.67	0.22	5.60	**0.06***
$dr \to for$ ‡	$H_{18} : dr \nrightarrow for$	18.7	**0.00*****	12.6	**0.00*****
$for \to y$	$H_{19} : for \nrightarrow y$	7.10	0.13	5.54	**0.06***
$i \to v$ ‡	$H_{20} : i \nrightarrow v$	10.4	**0.03****	8.07	**0.01****

*:Significant at 0.10. **:Significant at 0.05. ***:Significant at 0.01. ‡ indicates the relations being robust to filtering method. Includes all significant GC results.

Table 1.8: Block Exogeneity Wald Test Granger-Causal relations under low/high leverage specifications

Causality	**Null**	**Low Leverage**		**High Leverage**	
		Chi-sq	Prob.	Chi-sq	Prob.
$y \rightarrow k$ †	$H_1 : y \nrightarrow k$	8.69	**0.01****	9.41	**0.00*****
$y \rightarrow l$	$H_2 : y \nrightarrow l$	0.33	0.84	2.46	0.29
$y \rightarrow h$	$H_3 : y \nrightarrow h$	23.6	**0.00*****	2.46	0.29
$y \rightarrow v$	$H_4 : y \nrightarrow v$	0.29	0.86	7.85	**0.01****
$y \rightarrow dr$	$H_5 : y \nrightarrow dr$	0.00	0.99	11.5	**0.00*****
$k \rightarrow y$	$H_6 : k \nrightarrow y$	2.11	0.34	3.71	0.15
$k \rightarrow h$ †	$H_7 : k \nrightarrow h$	11.8	**0.00*****	9.62	**0.00*****
$k \rightarrow for$	$H_8 : k \nrightarrow for$	7.38	**0.02****	2.37	0.30
$l \rightarrow y$	$H_9 : l \nrightarrow y$	3.05	0.21	14.8	**0.00*****
$l \rightarrow k$ †	$H_{10} : l \nrightarrow k$	8.23	**0.01****	12.3	**0.00*****
$l \rightarrow h$	$H_{11} : l \nrightarrow h$	3.05	0.21	14.8	**0.00*****
$l \rightarrow v$	$H_{12} : l \nrightarrow v$	0.98	0.61	3.50	0.17
$l \rightarrow dr$	$H_{13} : l \nrightarrow dr$	1.14	0.56	19.3	**0.00*****
$h \rightarrow y$	$H_{14} : h \nrightarrow y$	1.06	0.58	4.71	**0.09***
$h \rightarrow k$ †	$H_{15} : h \nrightarrow k$	5.81	**0.05*****	4.60	**0.09***
$h \rightarrow dr$	$H_{16} : h \nrightarrow dr$	3.05	0.21	0.38	0.82
$h \rightarrow i$	$H_{17} : h \nrightarrow i$	1.27	0.52	9.04	**0.01****
$h \rightarrow v$ †	$H_{18} : h \nrightarrow v$	6.66	**0.03****	4.63	**0.09***
$dr \rightarrow k$ †	$H_{21} : dr \nrightarrow k$	31.9	**0.00*****	18.1	**0.00*****
$dr \rightarrow l$	$H_{22} : dr \nrightarrow l$	2.27	0.32	2.63	0.26
$dr \rightarrow for$	$H_{23} : dr \nrightarrow for$	6.42	**0.04****	3.00	0.22
$for \rightarrow y$	$H_{24} : for \nrightarrow y$	2.37	0.30	8.95	**0.01****
$for \rightarrow l$ †	$H_{25} : for \nrightarrow l$	5.68	**0.05***	5.02	**0.08***
$for \rightarrow h$	$H_{26} : for \nrightarrow h$	21.1	**0.00*****	0.81	0.66
$for \rightarrow v$	$H_{27} : for \nrightarrow v$	0.11	0.94	7.93	**0.01****
$for \rightarrow i$ †	$H_{28} : for \nrightarrow i$	5.57	**0.06***	4.71	**0.09***
$i \rightarrow y$	$H_{29} : i \nrightarrow y$	3.53	0.17	8.93	**0.01****
$i \rightarrow k$	$H_{30} : i \nrightarrow k$	0.65	0.71	12.34	**0.00*****
$i \rightarrow l$	$H_{31} : i \nrightarrow l$	2.92	0.23	6.74	**0.03****
$i \rightarrow v$	$H_{32} : i \nrightarrow v$	2.81	0.24	21.1	**0.00*****
$i \rightarrow dr$	$H_{33} : i \nrightarrow dr$	0.94	0.62	9.97	**0.00*****

*****:Significant at 0.10. ******:Significant at 0.05. *******:Significant at 0.01. † indicates the relations being robust to low/high household leverage. Includes all significant GC results.

Figure 1.15: Dummy-Augmented VAR Impulse Responses (Leverage dummy set to one)

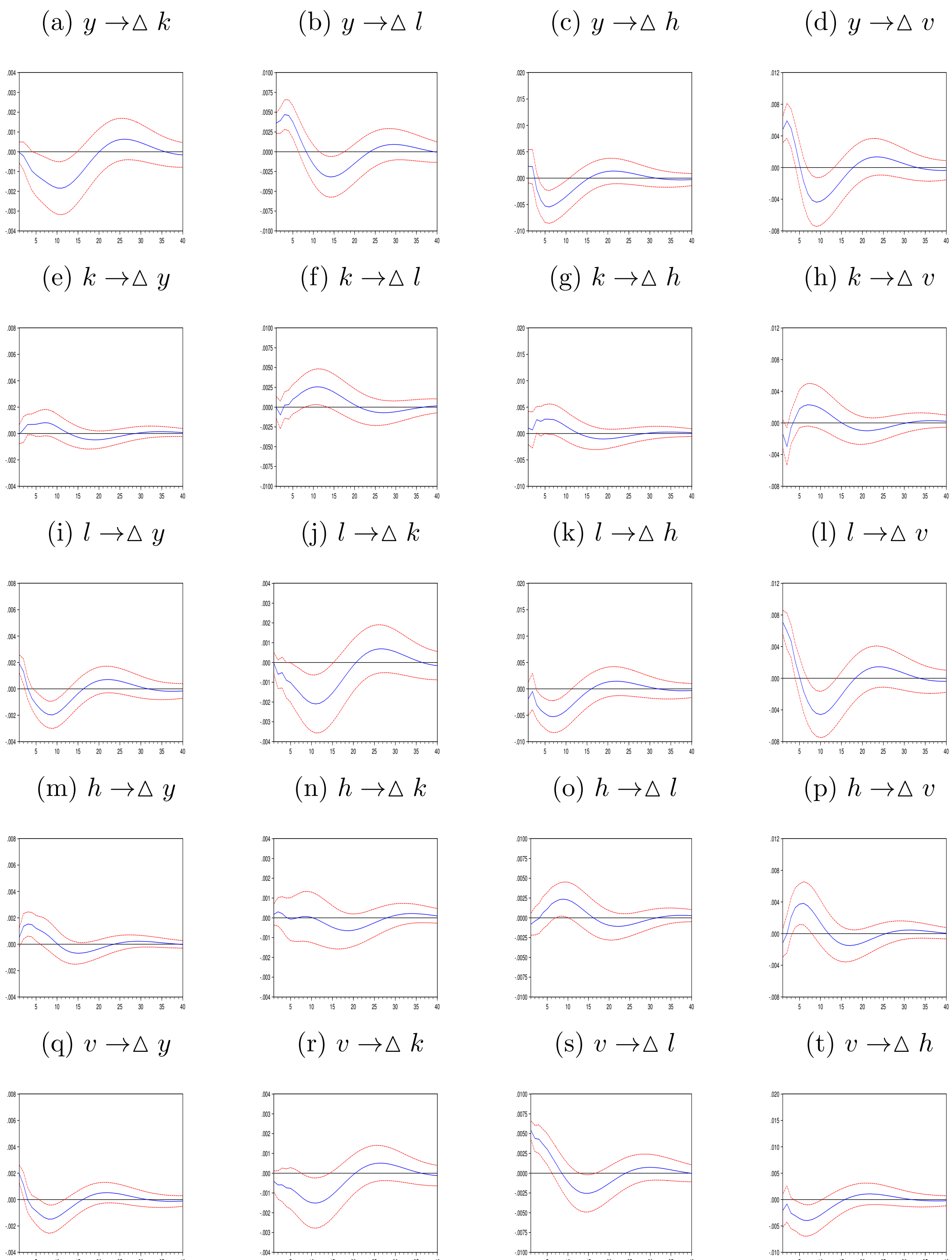
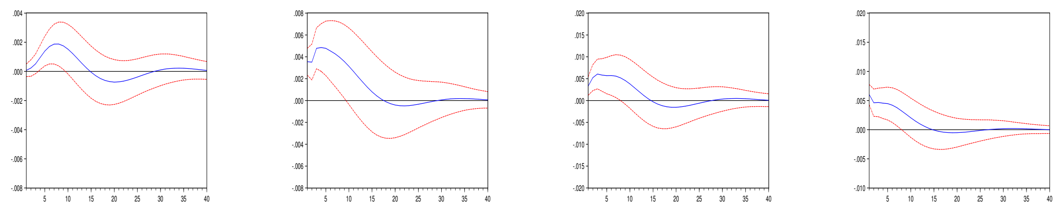
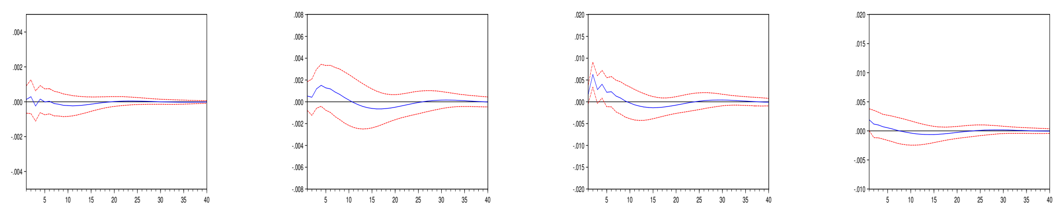


Figure 1.16: Dummy-Augmented VAR Impulse Responses (Leverage dummy set to zero)

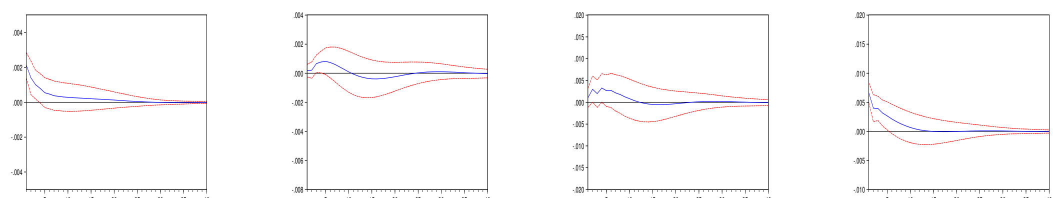
(a) $y \to \Delta\ k$ (b) $y \to \Delta\ l$ (c) $y \to \Delta\ h$ (d) $y \to \Delta\ v$



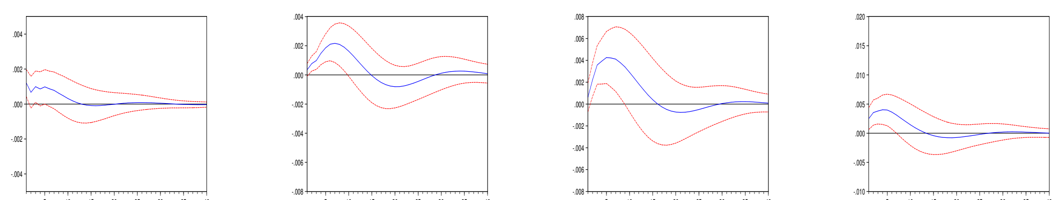
(e) $k \to \Delta\ y$ (f) $k \to \Delta\ l$ (g) $k \to \Delta\ h$ (h) $k \to \Delta\ v$



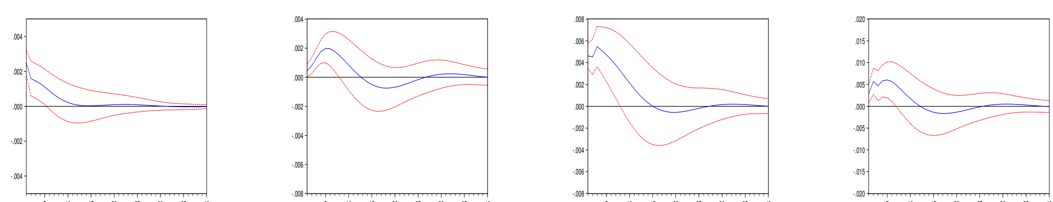
(i) $l \to \Delta\ y$ (j) $l \to \Delta\ k$ (k) $l \to \Delta\ h$ (l) $l \to \Delta\ v$



(m) $h \to \Delta\ y$ (n) $h \to \Delta\ k$ (o) $h \to \Delta\ l$ (p) $h \to \Delta\ v$



(q) $v \to \Delta\ y$ (r) $v \to \Delta\ k$ (s) $v \to \Delta\ l$ (t) $v \to \Delta\ h$



Chapter 2

Expectational Errors, Credit Supply Shocks and Collateral Constraints: When Good News Turns Bad

2.1 Introduction

Several studies purporting to explain the coincidental downturn of a range of macroeconomic variables have been published since the crisis.[1] However, the primary causal factors are still debated. One potential explanation is attributed to overly optimistic expectations on the part of both lenders and borrowers regarding the future path of asset prices. The argument that financial crises are caused in part by hubris is best exemplified by Minsky (1977, 1982, 1986, 1992) in which it is argued that expectations alone can induce asset and credit spirals. When new information arrives which invalidates agents' initial expectation, asset prices and credit volumes correct sharply

[1]For an overview of this literature interested readers are referred to Young (2014)

downward to their fundamental level.

Since the seminal contribution of Pigou (1927) there have been a range of arguments made for the explicit treatment of expectations in economic modelling.[2] As mentioned above, it has been argued that over-optimism contributed in a large part to the financial crisis. Indeed, optimism has long been posited as important feature of crisis episodes by economic historians (Kindleberger, 1978). Beaudry and Portier (2006, 2014) and Jaimovich and Rebelo (2009) show that changes in the expectations of agents in the form of so-called 'news shocks' regarding future productivity can help explain business cycle phenomena. In addition to news concerning future productivity, Christiano et al. (2010) incorporate financial news shocks in the BGG framework and find it to be an important determinant of demand. Exploiting survey data on expectations, Milani (2011) estimates that non-fundamental, or news, shocks are found to be a significant source of business cycle fluctuations. News shocks are exogenous changes to the information sets used by agents within the model with respect to the future path of economic variables. There are a range of techniques used to model changes to agents' information sets. News shocks can be extrinsic - i.e., some external event is expected to occur and agents perceptions to adapt to said change. Alternatively, a number of learning models have been developed in which changes to the information set are intrinsic and expectations follow an updating algorithm.

To date, there have been relatively few studies that examine expectational shocks in a DSGE model with collateral constraints. Using a neoclassical business cycle model, Inaba et al. (2007) show that news shocks to future TFP that turn out to be incorrect can generate boom-boom cycles in output in a model where firms can post both land and capital as collateral. Crucially, the response of land price does not exhibit similar boom-bust cycles: the variable returns to the steady state after the news shock turns out to have been false. Therefore, the model is unable to qualitatively

[2] For a survey of the literature on modelling expectations in macroeconomics, see Evans and Honkapohja (2001). For a survey of the literature on modelling expectations within a DSGE framework, see Milani (2012)

replicate the contemporaneous downturn in output and house prices observed during the recent crisis. Kobayashi and Nutahara (2007) go further showing that the same results can be obtained even by limiting a firm to posting only capital as collateral. Kanik and Xiao (2014) construct a monetary business cycle model and include collateral constraints on household borrowing. The authors examine the effect of a news shock to the marginal rate of substitution of housing against consumption and leisure. Although boom-bust cycles appear in output when the signal turns out to be incorrect, model simulations are unable to generate like behaviour contemporaneously in house prices.

This paper constructs a New-Keynesian DSGE model with multiple credit constraint agents. The model follows Iacoviello (2005) and is constituted of a lender (patient household), a borrower (impatient household), an entrepreneur, a retailer and a central bank. In this setting, borrowing is constrained by the value of house prices for the borrower, and constrained by the combined value of house prices and capital for the entrepreneur. Typically models allow for either non-firm specific assets (housing assets) or firm specific assets (capital) being posted by entrepreneurs as collateral. Using a dataset containing 8,820 firms spanning 15 countries, Liberti and Sturgess (2014) show that both are accepted by lending institutions as collateral. Calomiris et al. (2017) estimate the pledgibility of each type of asset class as collateral for a range of countries differentiated by legal structure. The parameters $\{\phi_h, \phi_k\}$ - the proportion of the value of each asset entrepreneurs can post as collateral - are calibrated from the aforementioned paper. The model allows us to exogenously shock the loan-to-value ratio which acts as a credit supply disturbance due to agents being credit constrained in and around the steady state. In order to examine whether shocks that alter agents' information sets can replicate qualitatively the behaviour of house prices and output during the recent crisis, the loan-to-value shock is subjected to an expectational shock. Two outcomes are subsequently examined. In the first, an anticipated news shock in which agents expect the future LTV ratio to loosen arrives as per agents initial expectations. In the second, the anticipated loosening does not occur causing agents to reassess their asset holdings. When expectations regarding a future loosening are incorrect, the model generates downward comovement in output, investment, consumption and house prices. Interestingly, simulation results show that allowing entrepreneurs to post both the housing asset and capital as collateral significantly amplifies the negative response of output and house prices relative to simulations in which either housing *or* capital can be posted as collateral.

The rest of the paper is laid out as follows. Section two motivates empirically the research question and model selection utilised below with a focus on the behaviour of macroeconomic variables prior to and during the crisis. Section three simulates a basic model highlighting the inability of existing models to replicate boom-bust behaviour in output and house prices in receipt of expectational shocks to the LTV ratio. Section four constructs and simulates the full model. Section five concludes and proposes areas of future research.

2.2 Data

Structural reform of financial markets in the 1980s facilitated a notable increase in financial activity. Using turning-point analysis, Drehmann et al. (2010) date the emergence of financial cycles - categorised by significant comovement in credit and asset price aggregates - to this period. U.S data in Table 2.1 below shows that the volatility of credit and asset price measures relative to output is higher in the subsample beginning in the mid 1980s than for the wider sample range, bar household debt. This provides somewhat tentative evidence that the aforementioned reforms significantly enhanced the cyclical variation in these variables.

Table 2.1: S.D Relative to Output

Sample	Household Debt	House Prices	Business Debt	Business Assets
Q1 1952 - Q4 2013	1.3475	2.3278	1.3701	1.4259
Q1 1985 - Q4 2013	1.2346	3.1405	2.4626	2.6820
Within sample Δ:	-8.4%	+34.9%	+79.7%	+88%

Indeed, statistically significant structural breaks are found in the time series of these variables during the 1980s.[3] Due to the dramatic increase in the variability of these variables in the last two decades, a number of papers have attempted to examine empirically the relationships between credit, asset prices and output. Goodhart et al. (2004) find that there are multi-directional links between each variable when analysing data from 17 industrialised economies. Constructing a U.S. dataset spanning 1985Q1-2013Q4 for output, household credit, business credit, house prices and business assets, Buchanan-Hodgman (2014) shows that the relationships between the aforementioned variables are, in the main, stronger during periods categorised by higher leverage. Importantly, the data show that house prices exhibit leading phase-shift in output over the sample periods and that during periods of high leverage changes house prices Granger-Cause changes in output, with the converse being rejected.

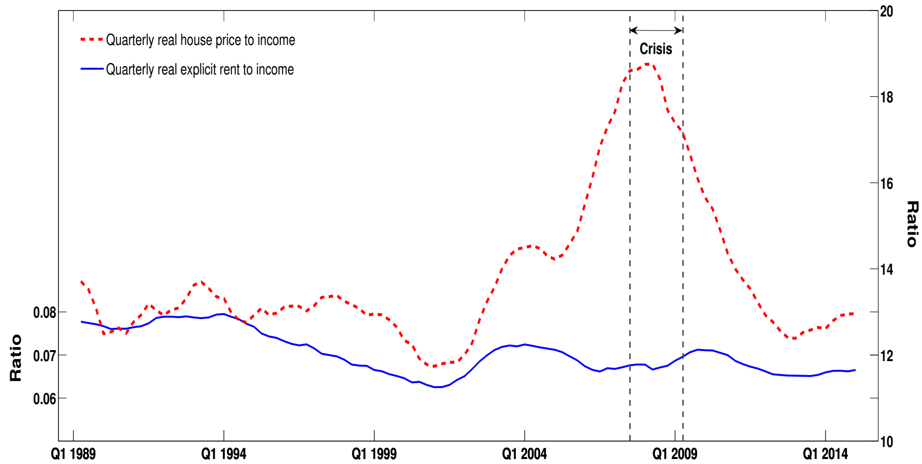
Existing structural models that attempt to provide an explicit role for credit aggregates and housing assets assume that holdings of the housing asset are impacted by one of two types of shocks; these shocks are either micro-founded or *ad hoc*. The former is in the form of a preference shock, impacting the marginal rate of substitution between housing and other elements of the utility function, usually consumption and leisure. The latter is by means of a term explicit in

[3] Buchanan-Hodgman (2014) utilises Bai-Perron Global L. breaks vs. none and Chow Tests showing that the breaks are Q2 1982, Q3 1987, Q1 1989 and Q2 1990 for the variables business assets, house prices, business credit and household credit, respectively. The data are for the U.S.

the housing asset price equations. These shocks gain traction through a collateral constraint by loosening a binding credit friction and enables an increase in borrowing. Estimates of the size of housing preference shocks tend to be very large and range between $\{24.89, 30.59\}$.[4] It is argued that large housing preference shocks such as these can explain upwards of 90% of the variance of house prices. However, if what are essentially housing demand shocks are the primary cause of the house price boom of the recent decade then we ought to observe in the data a concomitant increase in rents as these measure the housing service flow (Crone et al., 2009).

[4]These are sourced from Iacoviello (2005); Kanik and Xiao (2014).

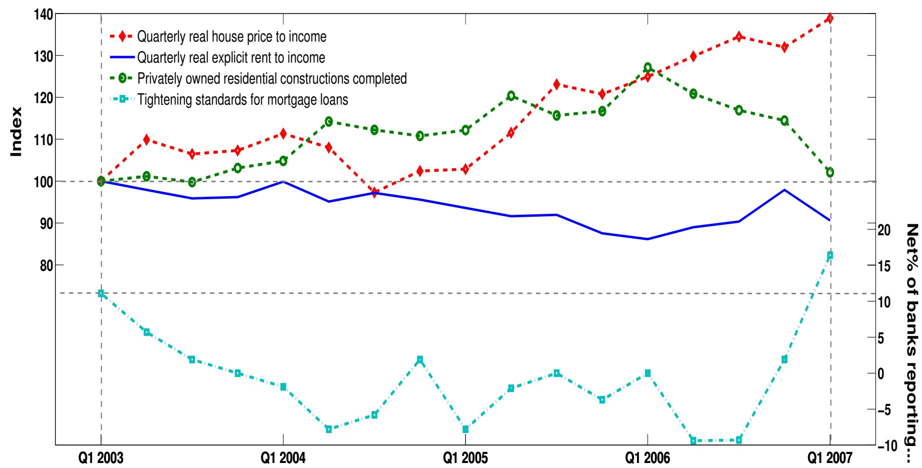
Figure 2.1: House Price v. Rents



Data: Current Population Survey/Housing Vacancy Survey, Series H-111, U.S. Census

Figure 2.1 above shows that rents in 2007 were roughly similar to those in 2001, whereas house prices rose from approximately 12 times income in 2001 to 18 times income in 2007. Assuming any housing demand shock would be symmetric across participants in the buying and rental markets, if the cause of the rise in property prices was a demand-side shock then rents, as measuring housing service flows, ought to have increased with some proportionality also. A potential explanation of this divergence between rents and prices is that of an adverse housing supply shock; however, this would require implausibly long rental contract agreements or a supply shock of this nature would result in proportional increase in rents also. Referring to Figure 2.2, we can see that there was no such shock to housing supply. Indeed we observe quite the reverse: privately owned residential constructions completed broadly track house prices during the 2003-2006 period, growing faster than price growth between Q1 2004 and Q2 2005.

Figure 2.2: Housing Supply or Credit Supply?



Additional data sources: U.S. Census - New Residental Constructions - Table 5. And Federal Reserve Board - Senior Loan Officer Opinion Survey on Bank Lending Practices

Figure 2.2 shows that throughout the period the net percentage of banks reporting quarter-on-quarter tightening in lending conditions for mortgage loans was on average decreasing. In Q1 2003 approximately +12% of banks reported a tightening of lending standards for mortgage applicants. This thrice fell to approximately −10%; first in Q2 2004, second in Q1 2005 and again in Q2-3 2006. Therefore, during the period categorised by a rapid growth in house prices, banks' lending standards for mortgages remained relatively loose as did their lending practices for consumer loans - excluding credit cards. This can be seen in Appendix D Figure 2.13 and shows a relative but pronounced loosening over the same time period.[5]

This indicates that, rather than explicit positive housing demand or negative housing supply shocks, attention should instead be directed to the effect of a loosening of lending standards on house prices and credit, and by extension the dynamic impact this has on real variables through a financial channel in a structural model. In light of this evidence, two benchmark models - one

[5]This empirical observance has important implications for the model and is explained below.

relatively simplistic, the other more involved - are constructed and augmented by the inclusion of credit supply shocks transmitted through the loan-to-value constraint.

2.2.1 The Introduction of Loan-to-Value Shocks

In order to examine the effect of a credit supply shock, otherwise standard collateral constraint models can be adapted to allow for shocks to the loan-to-value ratios - 'LTV' shocks hereafter. When the shock hits, agents that were initially constrained become able to increase their leverage against their respective holdings of collateral assets whether in the form of capital and/or housing.

A number of papers have found shocks in this form to have important implications for business cycle fluctuations (Jermann and Quadrini, 2012; Liu et al., 2013; Brzoza-Brzezina et al., 2013). However, the existing literature is yet to provide a statistical foundation as to how this shock should enter the model when there are two or more agents each being credit constrained. Do the data indicate credit supply shocks affect both borrowing households and businesses symmetrically? Or do the data indicate a divergence between the impact of a credit supply shock on households and businesses?

As data pertaining to the relative 'tightness' of the lending market is collected though surveying loan officers, it is inherently qualitative in its collection and therefore difficult to analyse formally due to the subjective nature of the responses by participants. Data for non-price terms of lending is collected for the following loan types: loans to large scale business, loans to medium scale business, loans to small scale business, household mortgage loans and consumer loans. Table 2.2 below shows the correlations in 'tightness' for these loan types;

Table 2.2: Matrix of Correlations: Non-Price Terms of Lending

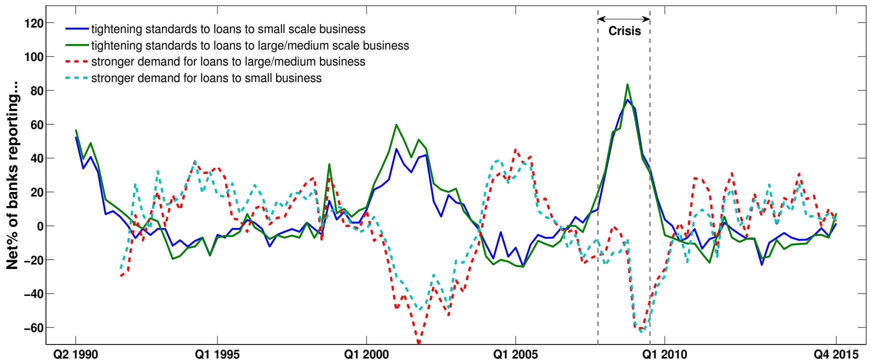
	Full Sample				Q1 2007 - Q4 2009			
Variable	L bus	M/S bus	Mort	Cons	L bus	M/S bus	Mort	Cons
L bus	1	0.96	0.81	0.50	1	0.98	0.96	0.89
M/S bus	0.96	1	0.73	0.50	0.98	1	0.96	0.91
Mort	0.81	0.74	1	0.37	0.96	0.96	1	0.91
Cons	0.50	0.50	0.37	1	0.89	0.91	0.91	1

Note: L bus: large business; M/S bus: medium/small business; Mort: mortgage lending; Cons: consumer loans. Data pertaining to the tightening of mortgage lending to households ends in 2007. For the subsample capturing the financial crisis, data for commercial real estate was used. Although not ideal, it is the closest substitute available. All data is from the SLOOS - available from the FRED.

The table shows that over the full sample range the correlation between conditions of business lending of all types and conditions for housing lending for all types are relatively moderate. This is particularly true of the correlation between conditions for business lending and that for household consumption. However, the correlations between all types of non-price terms of lending increases dramatically once the sample range under consideration is constrained to a time series subset incorporating the financial crisis. This indicates that during periods of heightened financial distress non-price terms of lending become much more interrelated and comove closely. Unsurprisingly, there is also a strong inverse relationship between non-price terms and loan demand, as evidenced in Figure 2.3 below. This could indicate that a significant determinant of credit creation is in non-price terms that are, in a large part, under the autonomy of individual lending institutions.

The relationships between these different variables have important implications for how a collateral shock is modelled. If the correlation between changes in business and household borrowing conditions was low then this would motivate the inclusion of a uniform collateral constraint shock - here acting as a non-price terms of lending shock. However, the data show that when non-price

Figure 2.3: Business Non-Price Terms of Lending: Tightening v. Demand



terms of lending tighten they do so somewhat symmetrically for business and household borrowing. Therefore, the collateral constraint shock in the full model below affects both borrowing household and entrepreneur jointly.

2.3 Basic Model

In order to examine the impact of a loosening of lending standards, a simple collateral constraint model is constructed.[6] The model below is populated by five types of agents: lending household, borrowing household, wholesalers, retailers and central bank. There are five commodities: lenders labour, borrowers labour, housing, consumption goods and bonds. The production function requires labour input from both types of household; intermediate output is in the form of an undifferentiated wholesale goods which the retailers differentiate at no cost and sell in the form of final consumption goods at a mark-up. Staggered price setting is introduced à la Calvo (1983).

The borrowing household is credit constrained in and around the steady state by the assumption that the lender is more patient than the borrower. The households have equivalent utility functions: they demand a housing asset, consumption good and leisure. The introduction of housing into the utility function assumes that households derive utility from housing service flow. Subscripts $\{1, 2\}$ differentiate lenders from borrowers.

2.3.1 Households

Lenders

The lender is assumed to have the following utility function;

$$E_0 \sum_{t=0}^{\infty} \beta_1^t \left(\ln C_{1,t} + d_t \ln h_{1,t} - \frac{L_{1,t}^{\eta}}{\eta} \right) \tag{2.1}$$

subject to;

[6]The model follows that of Kanik and Xiao (2014); their model follows loosely the framework in Iacoviello (2005).

$$C_{1,t} + q_{h,t}h_{1,t} + \frac{R_{t-1}b_{1,t-1}}{\pi_t} = b_{1,t} + q_{h,t}h_{1,t-1} + w_{1,t}L_{1,t} + F_t \tag{2.2}$$

where C_1 is lender consumption, q_h house price, h_1 the lenders holding of the housing asset, R the nominal interest rate, b_1 lenders holding of the one-period bond, π is inflation, w_1 is the lenders wage rate, L_1 the lenders labour and F lump-sum profits rebated by the retailers. Variables $\{q_h, b_1, w_1\}$ are in real terms. Crucially, d_t is a preference shock governing the marginal rate of substitution between the housing asset and consumption and leisure. This variable is common across household types.

The first order conditions for the lender household are as follows;

$$\frac{1}{C_{1,t}} = \lambda_{a,t} \tag{2.3}$$

$$\frac{q_{h,t}}{C_{1,t}} = \frac{d_t}{h_{1,t}} + \beta_1 \frac{q_{h,t+1}}{C_{1,t+1}} \tag{2.4}$$

$$L_{1,t}^{\eta-1} = \frac{w_{1,t}}{C_{1,t}} \tag{2.5}$$

$$\frac{1}{C_{1,t}} = \beta_1 \frac{R_t}{C_{1,t+1}\pi_{t+1}} \tag{2.6}$$

Borrowers

The borrower is assumed to have the following utility function;

$$E_0 \sum_{t=0}^{\infty} \beta_2^t \left(\ln C_{2,t} + d_t \ln h_{2,t} - \frac{L_{2,t}^{\eta}}{\eta} \right) \tag{2.7}$$

subject to;

$$C_{2,t} + q_{h,t}h_{2,t} + \frac{R_{t-1}b_{1,t-1}}{\pi_t} = b_{2,t} + q_{h,t}h_{2,t-1} + w_{2,t}L_{2,t} \tag{2.8}$$

$$b_{2,t} \leq m_t E_t\left(\frac{q_{h,t+1}h_{2,t}\pi_{t+1}}{R_t}\right) \tag{2.9}$$

the utility functions are identical in form for both households, the subscript 2 indicating a borrower and 1 indicates a lender. As the borrowing household does not own retailers, F is omitted from the budget constraint. Equation (2.9) is the collateral constraint, this limits the quantity of loanable funds available to the borrower to some ratio m_t of the expected real total value of collateral assets.

The first order conditions for the borrower household are as follows;

$$\frac{1}{C_{2,t}} = \lambda_{b,t} \tag{2.10}$$

$$\frac{q_{h,t}}{C_{2,t}} = \frac{d_t}{h_{2,t}} + \beta_2\frac{q_{h,t+1}}{C_{2,t+1}} + \lambda_{c,t}m_t q_{h,t+1}\pi_{t+1} \tag{2.11}$$

$$L_{2,t}^{\eta-1} = \frac{w_{2,t}}{C_{2,t}} \tag{2.12}$$

$$\frac{1}{C_{2,t}} = \beta_2\frac{R_t}{C_{2,t+1}\pi_{t+1}} - \lambda_{c,t}R_t \tag{2.13}$$

2.3.2 Wholesaler

The wholesaler maximises profit;

$$\frac{Y_t}{X_t} - w_{1,t}L_{1,t} - w_{2,t}L_{2,t} \tag{2.14}$$

subject to;

$$Y_t = L_{1,t}^{\alpha} L_{2,t}^{(1-\alpha)} \tag{2.15}$$

where X_t is the mark-up charged by retailers over that of the wholesaler; this results from the fact that retailers are monopolistically competitive. The production function is Cobb-Douglas.

The first order conditions for the wholesaler are as follows;

$$w_{1,t} = \frac{\alpha Y_t}{X_t L_{1,t}} \tag{2.16}$$

$$w_{2,t} = \frac{(1-\alpha) Y_t}{X_t L_{1,t}} \tag{2.17}$$

2.3.3 Retailer

The retailers problem is standard in the New-Keynesian literature and follows Iacoviello (2005). Monopolistically competitive retailers purchase goods from competitive wholesalers, differentiate said goods and sell at a mark-up. Where the aggregate price index is defined as elsewhere in the literature: $\left[\int_0^1 P_t(i)^{1-\epsilon} di\right]^{\frac{1}{1-\epsilon}} \equiv P_t$; the price of the wholesale good is $P_t^w = \frac{P_t}{X_t}$; and (i) variety-specific demand curve defined $Y_{i,t} = \left(\frac{P_{(i),t}}{P_t}\right)^{-\epsilon} Y_t$. Retailers maximise expected discounted profits, given the wholesale price and variety-specific demand curve;

$$\max_{P_t^*(i)} \sum_{k=0}^{\infty} \theta^k E_t \left\{ \beta_1^k \frac{C_{1,t}}{C_{1,t+k}} \left(\frac{P_t^*(i) - P_{t+k}^w}{P_{t+k}} Y_{t+k}^*(i) \right) \right\} = 0 \tag{2.18}$$

the resultant first order condition is;

$$\max_{P_t^*(i)} \sum_{k=0}^{\infty} \theta^k E_t \left\{ \beta_1^k \frac{C_{1,t}}{C_{1,t+k}} Y_{t+k} \left(\frac{P_t^*}{P_{t+k}} \right)^{-\epsilon} \left(\frac{P_t^*}{P_{t+k}} - \left(\frac{X}{X_{t+k}} \right) \right) \right\} = 0 \tag{2.19}$$

where β_1^k is the lending households discount factor, retailer profits are rebated in the form $F = \frac{X-1}{X}Y$ and the steady state markup is $X = (1-1/\epsilon)^{-1}$. Therefore, retailers set the price so expected discounted revenue and cost - i.e inverse of the mark-up - are equal. Finally, aggregate price level dynamics are given by;

$$P_t = \left[\theta P_{t-1}^{1-\epsilon} + (1-\theta) P_t^{*1-\epsilon} \right]^{\frac{1}{1-\epsilon}} \tag{2.20}$$

These equations are necessary to introduce sticky prices, and permits the analysis of monetary policy through the derivation of the New-Keynesian Phillips Curve.[7]

2.3.4 Central Bank

In this simplified model the central bank follows a Taylor-type interest rule targeting inflation only and is of the form;

$$R_t = \phi_\pi \pi_t \tag{2.21}$$

where ϕ is the reaction coefficient on inflation.[8]

2.3.5 Shock Processes

The model is subjected to two separate shocks specific to credit and housing: the first follows the literature concerning collateral constraints and is in the form of a positive housing preference shock

[7]The result is equivalent to that found in Gali (2008). A guide to the derivation linearised Phillips Curve can be found at `https://sites.google.com/site/buchananhodgman/lecture-notes`.

[8]This follows the specification in Kanik and Xiao (2014). Note that an alternate orthodox specification of the Taylor Rule - i.e., where the policy rate responds to output in addition to inflation - does not qualitatively alter the key results. However, it does act to dampen the initial response of output by around 40% compared with a pure inflation target.

(d_t); the second is a LTV shock (m_t).[9] The shocks are specified thus;

$$\widetilde{d}_t = \rho_d \widetilde{d}_{t-1} + \widetilde{\epsilon}_{d_t} \tag{2.22}$$

$$\widetilde{m}_t = \rho_m \widetilde{m}_{t-1} + \widetilde{\epsilon}_{m_t} \tag{2.23}$$

where both shocks follow AR(1) processes with autocorrelation coefficients governed by ρ and $\widetilde{\epsilon}$ the standard deviations of each shock. The housing demand shock given by equation (2.21) increases the demand for housing on the part of households; the LTV shock given by equation (2.22) increases the amount of funds the credit constrained household can access by relaxing the borrowing constraint.

2.3.6 Equilibrium

The competitive equilibrium is a sequence of prices $\{w_{1,t}, w_{2,t}, R_t, q_{h,t}, P_t, X_t\}$ and allocations $\{C_{1,t}, C_{2,t}, h_{1,t}, h_{2,t}, L_{1,t}, L_{2,t}, Y_t, b_{1,t}, b_{2,t}\}_{t=0}^{\infty}$ such that, taking prices as they are, the allocation yields the solution to the agents' respective optimising problems and markets clear. The endogenous state variables are $\{R, h_2, b_2\}$, with exogenous state variables $\{d, m\}$.

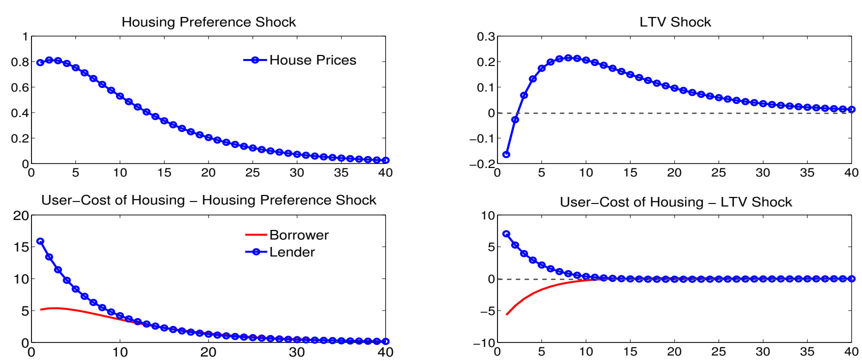
2.3.7 Results

The impulse responses to a collateral constraint shock are relatively similar to those obtained through a housing preference shock. Aggregate consumption, aggregate labour and lending volumes increase on impact. When a LTV shock hits, borrowers immediately increase their borrowing. A wealth effect causes borrowers to accumulate more housing, consume more and reduce labour hours.

[9] All model equations are contained in Appendix A below.

The same results are obtained when a housing preference shock hits. The absence of a housing production sector implies a fixed supply of the housing asset; therefore, an increase in holdings of the housing asset on the part of impatient households requires a reduction in holdings on the part of patient households. It is clear from Figure 2.4 that in the case of a housing preference shock the user-cost[10] of housing for the borrower increases less than does for the lender. This is because the shadow cost of borrowing has fallen, directly affecting the borrower and not the lender. Therefore, the holdings of the housing asset shift in favour of the borrower. This results because the housing asset plays a pivotal role for the borrower in the form of relaxing the borrowing constraint. On examination of the LTV shock, it is apparent that the user-cost for the lender and borrower diverge. As the LTV shock directly affects the collateral constraint it lowers the user-cost for the borrower. As in the case of a housing preference shock, the borrower accumulates housing assets at the expense of the lender.

Figure 2.4: Housing Preference v LTV Shock: User-Costs



A shock to the LTV constraint implies through the borrowing constraint an immediate increase in lending with the lender increasing labour hours and decreasing consumption. The reaction coefficient on inflation in the Taylor Rule is 1.2, thus the interest rate response is in excess of the change in inflation causing a real rate rise incentivising saving(lending) behaviour. Aggregate

[10]The user cost for the lender is increasing in house prices and the real interest rate, while decreasing in expected house price appreciation. The same is true for the lender, however the additional components λ and m must be added to account for the collateral constraint. See Appendix A.

labour increases as the positive response of the lender in labour hours is in excess of the negative response in borrowers labours hours. Similarly, the wealth effect for borrowers causes an increase in consumption that more than offsets the reduction in lenders consumption required to facilitate the higher level of lending.

The comovement of output, consumption and labour hours in response to a housing preference shock requires a steady state loan-to-value ratio in excess of 0.63. When the loan-to-value ratio is below this figure, a housing preference shock induces a strong substitution effect: output, consumption and labour hours fall as agents substitute in favour of an accumulation of the housing asset as the borrowing constraint is tighter.[11]

In order to examine whether overly optimistic forecasts of the path of housing demand or credit market conditions can replicate cyclical behaviour in output and housing prices, news shocks are introduced into the model above. News shocks require augmenting the exogenous shock processes for housing preference (d_t) and the loan-to-value ratio (m_t). Agents receive a signal in period $t-n$ regarding a future shock to $\{d_t, m_t\}$ in t periods time. Formally, the exogenous processes governing housing preference shocks and a collateral shocks are augmented thus;

$$\widetilde{m}_t = \rho_m \widetilde{m}_{t-1} + \widetilde{\upsilon}_{m_t} \tag{2.24}$$

$$\widetilde{d}_t = \rho_d \widetilde{d}_{t-1} + \widetilde{\upsilon}_{d_t} \tag{2.25}$$

where;

$$\widetilde{\upsilon}_{m,t} = \epsilon_{m,t} + \epsilon_{m,t-n} \tag{2.26}$$

$$\widetilde{\upsilon}_{d,t} = \epsilon_{d,t} + \epsilon_{d,t-n} \tag{2.27}$$

[11] There are a wide range of values for the LTV ratio for the borrowing household. Estimates provided in the literature are, *inter alia*, 0.55 (Iacoviello, 2005), 0.7 (Gerali et al., 2010), 0.85 (Iacoviello and Neri, 2010) and 0.9 (Kanik and Xiao, 2014).

The change in the information set that this represents causes agents to adapt their current behaviour in expectation of the realisation of the future shock. This framework allows the examination of two scenarios. The first is when the news shock is correct. In the event of a correct news shock - i.e., the shock materialises in period t and the model returns gradually to the steady state. The second is when the news shock does not materialise and expectations are frustrated - i.e., $\epsilon_{\{m,d\},t}$ precisely offsets the earlier signal $\epsilon_{\{m,d\},t-n}$. The result of this second scenario can be interpreted as agents' having been incorrect in period $t-n$ in their anticipation of a future shock. Of particular interest is whether when an unanticipated shock that precisely offsets the earlier anticipated shock to either housing preferences or the LTV ratio are able to generate downward comovement in a range of macroeconomic variables, specifically a downturn in house prices.

Figure 2.5: News Shocks: Housing Preference v. LTV

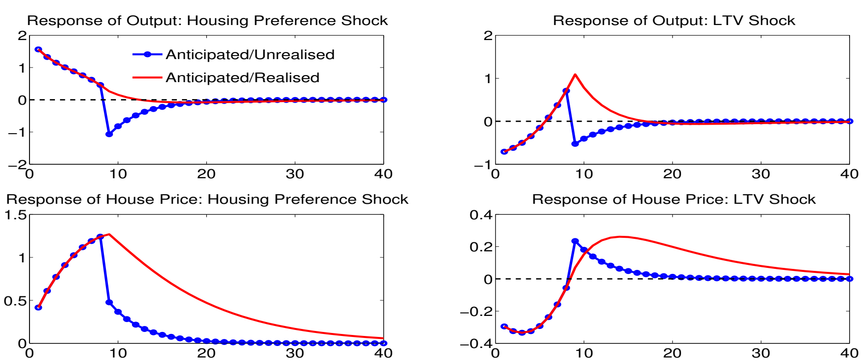


Figure 2.5 below highlights the response of output and house prices to anticipated shocks to housing preferences and the LTV ratio both for the case where the anticipated shock is not offset by an unanticipated shock and when it is. The news shock is received in period $t-8$, with agents made aware of the incorrect signal in period $t=0$. Kanik and Xiao (2014) show that when a housing preference shock has been 'incorrect' the model exhibits boom-bust behaviour in output, as can be seen in the two sub-figures. However, the response of house prices does not exhibit the same cyclical behaviour - after a housing preference shock, house prices return to their initial steady

state without overshooting. In the case of LTV shocks, the response of both output and house prices falls initially becoming positive as we converge to the period when the anticipated shock has been signalled to occur. In the event that it is offset by an unanticipated shock, output again falls below the steady state value. However, as with the housing preference shock house prices return to their initial steady state. Therefore, the model is unable to replicate cyclical and contemporaneous behaviour in both house prices and output.

2.4 Full Model

The basic model above has a number of shortcomings. Firstly, the model contains only one credit constrained agent. In response to a housing preference or LTV shock households simply reallocate housing between themselves with no direct effect on the firm. Secondly, the model does not include capital. Therefore, it is not possible to observe whether investment co-moves with output and consumption. Thirdly, as capital is not included in the model it does not allow for the construction of a more plausible collateral constraint in which agents are able to post collateral in the form of housing and capital. The final problem of the model is the inability to produce boom-bust cycles in output and house prices, the like of which we observed during the recent crisis when subjected to either housing preference or LTV shocks.

The above basic model is extended a number of ways in order to rectify the aforementioned shortcomings. An entrepreneur is introduced in place of the wholesaler and a production function is specified requiring labour, capital and housing as inputs. In order to enrich the dynamics further, the entrepreneur is credit constrained but is able to post both his housing assets and capital stock as collateral against borrowing. As there are now multiple credit constrained agents the introduction of the LTV shock is an important consideration. Given the highly correlated behaviour of non-price terms of lending reported by senior loan officers during periods of heightened financial stress, the LTV shock is introduced as a general shock impacting both the borrowing household and entrepreneur. This acts as a *de facto* aggregate credit supply shock. Crucially, the model is again subjected to news shocks in the form of correct and incorrect signals regarding the future path of housing preferences and the LTV ratio.

2.4.1 The Entrepreneurs Problem

The entrepreneurs problem follows loosely Iacoviello (2005). Entrepreneurs gain utility from consumption and aim to maximise;

$$E_0 \sum_{t=0}^{\infty} \gamma^t \ln C_{3,t} \tag{2.28}$$

The entrepreneur has a production function of the form;

$$Y_t = A_t K_{t-1}^{\mu} h_{3,t-1}^{\nu} L_{1,t}^{\alpha(1-\mu-\nu)} L_{2,t}^{(1-\alpha)(1-\mu-\nu)} \tag{2.29}$$

where K_{t-1}^{μ} is last periods capital, and $h_{3,t-1}^{\nu}$ is the entrepreneurs holding of last periods housing. The capital stock evolves according to;

$$K_t = I_t + (1-\delta)K_{t-1} \tag{2.30}$$

where δ is the depreciation rate of capital. The entrepreneur faces capital installation costs of the form $\Lambda_{k,t} = \frac{\psi_k}{2\delta}\left(\frac{I_t}{K_{t-1}} - \delta\right)^2 K_{t-1}$. The budget constraint of the entrepreneur is;

$$\frac{Y_t}{X_t} + b_{3,t} + q_{h,t}h_{3,t-1} = C_{3,t} + q_{h,t}h_{3,t} + \frac{R_{t-1}b_{3,t-1}}{\pi_t} + w_{1,t}L_{1,t} + w_{2,t}L_{2,t} + I_t + \Lambda_{k,t} + \Lambda_{h,t} \tag{2.31}$$

where the additional component $\Lambda_{h,t} = \frac{\psi_{3,h}}{2}\left(\frac{h_{3,t}-h_{3,t-1}}{h_{3,t-1}}\right)^2 q_{h,t}h_{3,t-1}$ is a housing adjustment cost. The borrowing constraint for the entrepreneur is given by;

$$b_{3,t} = \frac{\beta_1 \pi_{t+1} m_{3,t}(\phi_h q_{h,t+1} h_{3,t} + \phi_k q_{k,t+1}(1-\delta)K_t)}{R_t} \tag{2.32}$$

where $q_{k,t+1}$ is the price of capital.[12] The collateral constraint allows for the posting of housing assets and capital as collateral. The parameters $\{\phi_h, \phi_k\}$ are ratios of the housing asset and capital, remaining after depreciation, that can be posted as collateral by the entrepreneur, respectively. Including these components in the entrepreneurs collateral constraint allows us to vary the entrepreneurs ability to post either housing or capital as collateral and compare the dynamics.

Other than the addition of the entrepreneur, two other minor changes have been made to the basic model. Housing adjustment costs have also been applied to the borrower and the lender. The central bank now follows a Taylor-type rule responding to deviations in output and inflation in period $t-1$, the interest rate also suffers from inertia. The log-linearised version of the Taylor-rule is of the form;

$$\widetilde{R}_t = r_R \widetilde{R}_{t-1} + (1+r_\pi)(1-r_R)\widetilde{\pi}_{t-1} + r_Y(1-r_R)\widetilde{Y}_{t-1} + \widetilde{e}_{R,t} \tag{2.33}$$

where $\{r_\pi, r_Y\}$ are the reaction coefficients for deviations in inflation and output, and r_R is the degree of interest rate inertia. $\widetilde{e}_{R,t}$ is an exogenous monetary policy shock.[13]

The full set of model equations can be found in Appendix 2.A.

[12] The derivation of the price of capital follows Liu et al. (2013) and is contained in the entrepreneurs problem, although the resultant Tobin's q is equivalent to an explicit derivation found in models which incorporate a capital goods producer.

[13] The specification and parameterisations are borrowed from Iacoviello (2005).

2.4.2 Results

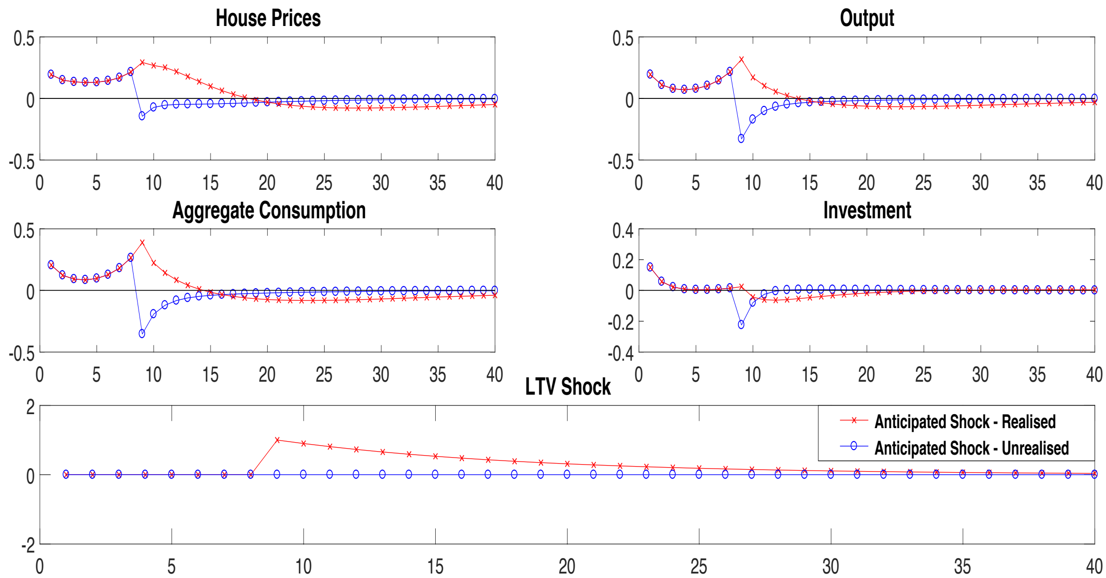
The collateral constraint in the entrepreneur problem allows the individual loan-to-value ratios of housing and capital to differ. Estimates of the ability to post capital as collateral vary significantly with jurisdiction and the relative strength of the respective legal systems. The ability to post moveable assets as collateral - in this context, capital - in the form of machinery, inventories and accounts receivables has been estimated for a wide selection of countries. Using a sample of 4,224 borrower from 12 strong- and weak-law countries between 2002-2004, Calomiris et al. (2017) estimates the pledgability of collateral in the form of capital to be 0.683. This calculation is taken from Table A.2 of the aforementioned paper. The figure 0.683 is calculated by taking an average of the full-sample estimates of the loan-to-value for machinery and inventory and accounts receivable subheadings. The authors also provide estimates for the loan-to-value for immoveable collateral - i.e., real estate. Similarly to moveable capital the estimates vary between strong- and weak-law states, with a full sample estimate of 0.864.[14] Therefore, the baseline calibrations for $\{\phi_k, \phi_h\}$ are 0.683 and 0.864 in the benchmark model simulation.[15]

The simple model above, on receipt of frustrated news shock to the LTV ratio, is not able to generate boom-bust behaviour in output and house prices. Indeed the model returns a fall in both output and house prices when an anticipated shock hits. Figure 2.6 shows the responses for a number of variables both in the case where the anticipated news shock is realised and where it is precisely offset by an unanticipated news shock in period 8. We can see that output, house prices and aggregate consumption individually exhibit boom-bust behaviour.

[14] Calibrations of this figure vary in the literature between 0.7 (Gerali et al., 2010) and 0.9 (Iacoviello, 2005).

[15] Performance of the full model and related steady state rations can be found in Table 2.5 and Table 2.6 below.

Figure 2.6: News Shocks: LTV: Impulse Responses

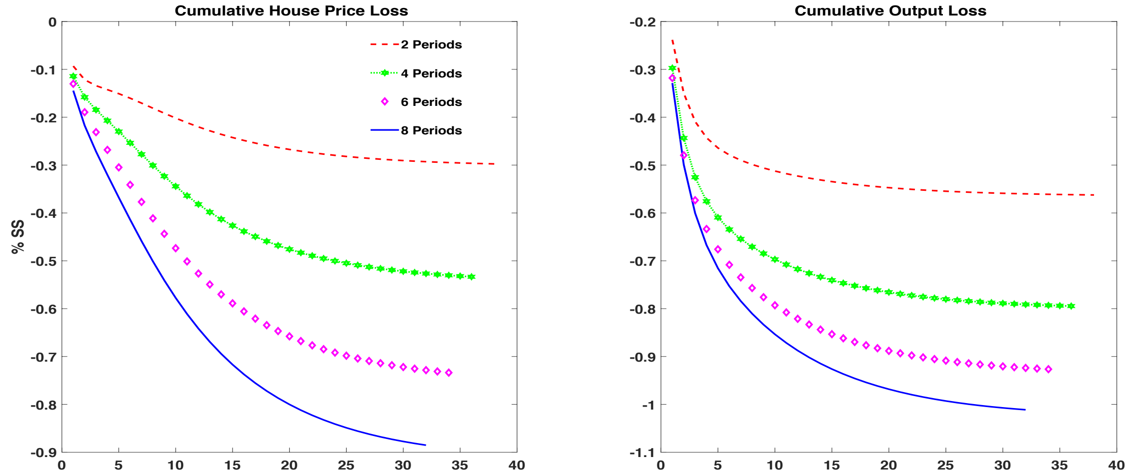


However, there is currently no consensus in the literature regarding the anticipation horizon of a news shock. Much of the existing literature focuses on a news shock to TFP over a variety of anticipation horizons: Barsky and Sims (2011) propose 3 periods; Krusell and McKay (2010) 5; and Beaudry and Portier (2014) 8 to 10. Therefore, in order to gauge the robustness of the results the model's anticipated horizon was varied over $\{8, 6, 4, 2\}$ periods. In each case the model was subjected to a news shock to the LTV ratio received in period $(t - \{8, 6, 4, 2\})$ and precisely offset in period t. In each simulation the loss in output and house price from the period in which the signal is shown to have been false - i.e., 2,4,6,8 - is calculated and can be seen in Figure 2.7.

We can see from Figure 2.7 that the cumulative losses in output and house prices are increasing in the anticipation horizon, albeit at a diminishing rate. The output and house price losses at a four period anticipated horizon are 57% and 61% greater than at a two period horizon, respectively; falling to 27% and 45% as we move the news shock from a six period to an eight period horizon. In all cases the loss to house prices exceeds that of output by a margin of approximately 20%.[16]

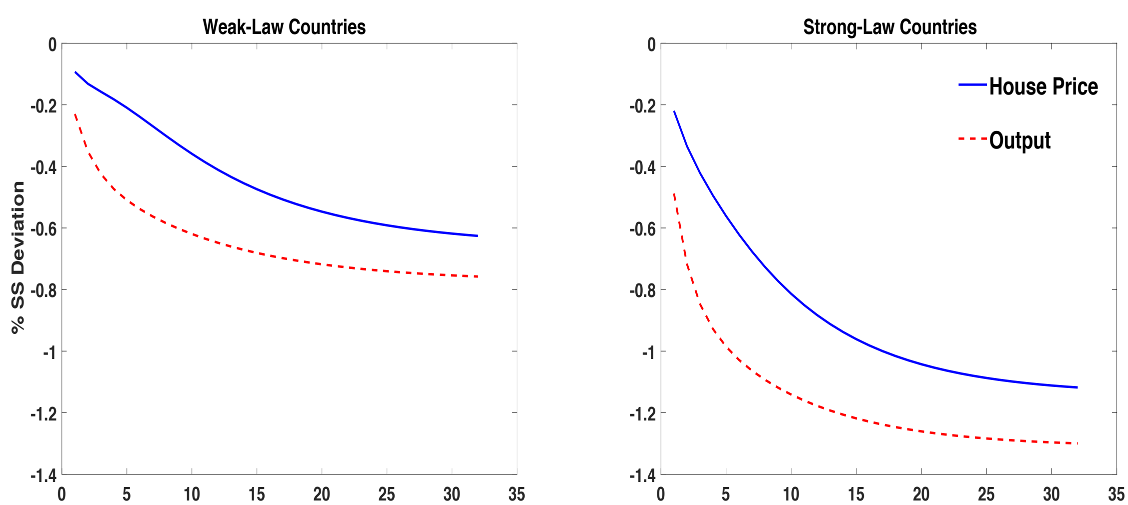
[16]The lines grow progressively longer as we move from 2 to 8 period ahead news shocks. This is due to the model being simulated for 40 periods, and taking the cumulative loss to begin in the period after the news shock has been offset.

Figure 2.7: News Shocks: LTV: Cumulative Losses



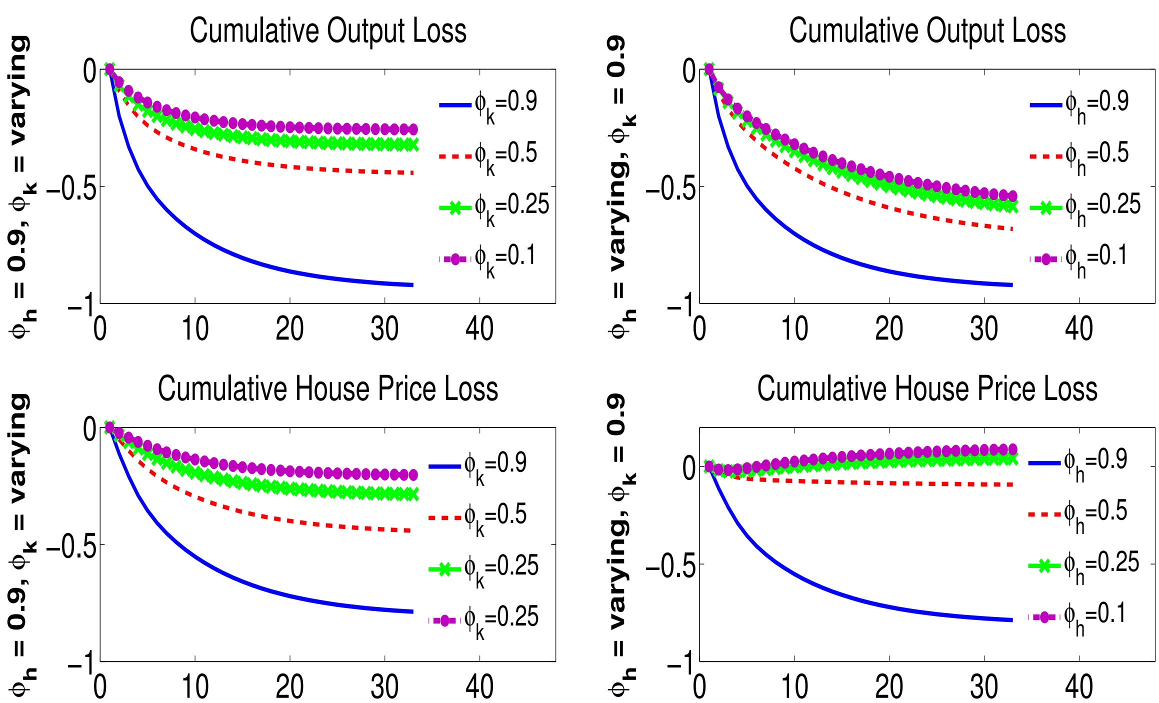
The cumulative loss to house prices and output given by the solid line in Figure 2.7 above were produced as a benchmark case using the calibrations for an 8-period ahead news shock. In order to examine the robustness of the contemporaneous downturns in house price and output in response to a LTV shock, two experiments are conducted. First, the pledgibility parameters $\{\phi_h, \phi_k\}$ are set at the average values for both weak-law and strong-law countries laid specified in Calomiris et al. (2017). Second, the robustness of the results is tested over a wider range of theoretical values of the pledgibility constraints - i.e., $\{(\phi_h, \phi_k) = 0.9, 0.5, 0.25, 0.1\}$.

Figure 2.8: News Shocks: LTV: Weak and Strong Law Jurisdictions



The supply of credit is sensitive to the ability of lenders to enforce contracts with borrowers. As shown by Fleisig et al. (2006), emerging market financial institutions are reluctant to accept moveable assets as collateral against lending, thereby adversely impacting credit supply. Figure 2.8 above provides the results for model simulations for weak-law and strong-law jurisdictions. In both cases output and house price still exhibit contemporaneous downturns. However, the cumulative losses in house prices and output are, respectively, 90% and 72% more when using the calibrations for the pledgibility constraints under strong-law jurisdiction.

Figure 2.9: News Shocks: LTV: Varying Pledgability Constraints



From Figure 2.9 above we can see that when $\phi_k = 0.9$ the cumulative losses of output and house prices are far in excess of those when the ability of the entrepreneur to post capital as collateral is lower. The response of house prices when the news shock is offset in the case of low values of ϕ_k is much diminished, although still negative over the entire range. Higher values of ϕ_k notably amplify the negative response of output; this negative response doubles as ϕ_k increases from 0.5

to 0.9. In the case of varying ϕ_h - the ratio of the housing asset that the entrepreneur is able to post as collateral - the cumulative output loss is less dispersed. Allowing the entrepreneur to post 10% of the housing asset as collateral, while allowing 90% of the value of capital can only result in a cumulative loss of around 50% of the total loss under a scenario where both $\{\phi_{h,k}\} = 0.9$. With regard the loss to house prices, it is clear that the result relies on the ability to post a relatively large fraction of the value of the housing asset as collateral in order to generate substantive losses.[17]

Therefore, the loss in output due to a news shock to the LTV ratio is amplified when the ability to post capital is higher than that of the housing asset. This is evidenced by the differing responses on the top line of Figure 2.9. To generate losses in house price, the entrepreneur must be able to post a significant proportion of the housing asset as collateral. In instances where the entrepreneur is not able to do so, the cumulative losses are negligible. However, the response is amplified by the ability to post both assets as collateral and increasing the pledgability of both. Finally, it is clear that cumulative losses in output and house prices are highest when the entrepreneur is able to post 90% of the total value of both as collateral against lending.

2.5 Conclusion

The paper constructed a New-Keynesian DSGE model with multiple credit constrained agents in order to examine qualitatively the impact of expectational shocks to the LTV ratio. The paper finds that, if agents expectations regarding a future loosening of the LTV ratio are precisely offset by an unanticipated shock, output, consumption, investment and house prices all decline sharply. By introducing a collateral constraint that allows entrepreneurs to post both housing and capital

[17]The cumulative 'losses' in the bottom right-hand graph are actually gains. This results from the transformation before taking the cumulative sum of the response post-news shock. The response for low parameterisations of ϕ_h becomes negative before the unanticipated news shock offsets the earlier anticipated news shock. Therefore, after normalising for the period in which the news shock is offset, the cumulative 'losses' move in the opposite direction

against any lending we are able to examine the sensitivity of the response of output and house prices over a range of different leverage limits. The paper tests the robustness of the results of a wide range of parameterisations of the pledgibility of capital and housing and for news shocks of varying anticipation horizons. When calibrated for weak-law and strong-law countries alternately, the paper finds that the strength of the downturn in output and house prices is robust under both parameterisations. However, the downturn is amplified in the case of strong-law countries characterised by high leverage ratios. Varying over a theoretical range of parameterisations, the paper finds that the cumulative loss of output is amplified dramatically when entrepreneurs are able to post 90% of the total value of both housing assets and capital relative to the case where only housing can be posted. The model also indicates that in order to generate significant comovement of output and house prices, entrepreneurs must be able to post a substantial proportion of the total value of their housing assets. In the case where entrepreneurs are able to post capital only, when an expectational shock hits only output declines with no comovement in house prices. Therefore, the resultant boom-bust behaviour in both variables in response to a frustrated expectational shock to the LTV requires entrepreneurs to post substantial quantities of both housing and capital. Results also show that the contemporaneous downturn is robust over the horizon set simulated, albeit diminishing as the horizon between the anticipated shock and the offsetting shock shortens.

Future research should be aimed in two directions. Firstly, the paper provides a useful framework in which to examine the efficacy of macro-prudential policy aimed at utilising the LTV ratio as a potential instrument. And secondly, a nonlinear model could be constructed in which expectational shocks hit the system away from the steady state - primarily when there are large credit-output gaps or high leverage ratios.

2.A Appendix

Steady State Equations - Basic Model

$$\pi = 1 \tag{2.34}$$

$$\beta_1 = \frac{1}{R} \tag{2.35}$$

$$\lambda_c = \frac{\beta_1 - \beta_2}{C_2} \tag{2.36}$$

$$q_h = \frac{d_1}{(1-\beta_1)} \frac{C_1}{h_1} \tag{2.37}$$

$$q_h = \frac{d_2}{(1-\beta_2-(\beta_1-\beta_2)m_2)} \frac{C_2}{h_2} \tag{2.38}$$

$$w_1 L_1 = \alpha \frac{Y}{X} \tag{2.39}$$

$$w_2 L_2 = (1-\alpha) \frac{Y}{X} \tag{2.40}$$

$$b_2 = \beta_1 m q h_2 \tag{2.41}$$

$$C_1 = (1-r)b_1 + \alpha \frac{Y}{X} + \left(1 - \frac{1}{X}\right) Y \tag{2.42}$$

$$C_2 = (1-r)b_2 + (1-\alpha) \frac{Y}{X} \tag{2.43}$$

$$\kappa = \frac{(1-\theta)(1-\beta_1\theta)}{\theta} \tag{2.44}$$

$$\frac{q_h h_1}{Y} = \frac{d}{(1-\beta_1)} \left(\alpha \frac{1}{X} + 1 - \frac{1}{X}\right) - (1-r)\beta_1 m \frac{d}{(1-\beta_2-(\beta_1-\beta_2)m + d(1-r)\beta_1 m)} (1-\alpha)(1/X) \tag{2.45}$$

$$\frac{q_h h_2}{Y} = \frac{d}{(1-\beta_2-(\beta_1-\beta_2)m + d(1-r)\beta_1 m)} (1-\alpha)(1/X) \tag{2.46}$$

$$\frac{C_1}{Y} = \left(\alpha \frac{1}{X} + 1 - \frac{1}{X}\right) - (1-r)\beta_1 m \frac{d}{(1-\beta_2-(\beta_1-\beta_2)m + d(1-r)\beta_1 m)} (1-\alpha)(1/X) \tag{2.47}$$

$$\frac{C_2}{Y} = -(1-r)\beta_1 m \frac{d}{(1-\beta_2-(\beta_1-\beta_2)m + d(1-r)\beta_1 m)} + (1-\alpha)\frac{1}{X} \tag{2.48}$$

$$\tag{2.49}$$

$$\frac{b_2}{Y} = \beta_1 m \frac{d}{(1 - \beta_2 - (\beta_1 - \beta_2)m + d(1 - r)\beta_1 m)} (1 - \alpha) (1/X) \tag{2.50}$$

$$\frac{h_2}{h_1} = \frac{\frac{q_h h_2}{Y}}{\frac{q_h h_1}{Y}} \tag{2.51}$$

$$\frac{C_1}{Y} = 1 - \frac{C_2}{Y} \tag{2.52}$$

Table 2.3: Basic Model Calibrated Parameter Values

Parameter	Description	Value	Source
β_1	Patient HH discount factor	0.99	Iacoviello (2005)
β_2	Impatient HH discount factor	0.98	Iacoviello (2005)
α	Patient HH labour share	0.5	Kanik and Xiao (2014)
d	Weight on housing in utility function	0.1	Iacoviello (2005)
η	Frisch elasticity of labour supply	1.01	Kanik and Xiao (2014)
θ	Calvo stickiness	0.75	Kanik and Xiao (2014)
ϕ_π	Reaction coefficient on inflation	1.2	Kanik and Xiao (2014)
ρ_D	Autocorrelation of housing preference shock	0.85	Kanik and Xiao (2014)
ρ_M	Autocorrelation of collateral constraint shock	0.85	-
m	Loan-to-Value ratio	0.9	Iacoviello (2005)
X	Steady state mark-up	1.05	Kanik and Xiao (2014)
r	Steady state interest rate	1.0101 ($1/\beta_1$)	Iacoviello (2005)

Linearised Equations

$$\widetilde{Y}_t = \frac{C_1}{Y}\widetilde{C}_{1,t} + \frac{C_2}{Y}\widetilde{C}_{2,t} \tag{2.53}$$

$$\widetilde{C}_{1,t} = \widetilde{C}_{1,t+1} + \widetilde{\pi}_{t+1} - \widetilde{R}_t \tag{2.54}$$

$$\beta_1\widetilde{C}_{2,t} = \beta_2\widetilde{\pi}_{t+1} + \beta_2\widetilde{C}_{2,t+1} - (\beta_1 - \beta_2)\widetilde{\lambda}_{c,t} - \beta_1\widetilde{R}_t \tag{2.55}$$

$$\widetilde{b}_{2,t} = \widetilde{M}_t + \widetilde{q}_{h,t+1} + \widetilde{\pi}_{t+1} + \widetilde{h}_{2,t} - \widetilde{R}_t \tag{2.56}$$

$$\widetilde{Y}_t = \widetilde{C}_{1,t} + \eta\widetilde{L}_{1,t} + \widetilde{X}_t \tag{2.57}$$

$$\widetilde{Y}_t = \widetilde{C}_{2,t} + \eta\widetilde{L}_{2,t} + \widetilde{X}_t \tag{2.58}$$

$$-\widetilde{h}_{1,t} = \frac{h_2}{h_1}\widetilde{h}_{2,t} \tag{2.59}$$

$$\begin{aligned}\frac{b_2}{Y}\widetilde{b}_{2,t} &= \frac{C_2}{Y}\widetilde{C}_{2,t} + \frac{q_h h_2}{Y}(\widetilde{h}_{2,t} - \widetilde{h}_{2,t-1}) + \frac{Rb_2}{Y}(\widetilde{R}_{t-1} - \widetilde{\pi}_t + \widetilde{b}_{2,t-1}) \\ &+ \left[(1-\alpha)\frac{1}{X}\right](\widetilde{Y}_t - \widetilde{X}_t)\end{aligned} \tag{2.60}$$

$$\widetilde{R}_t = r_\pi\widetilde{\pi} \tag{2.61}$$

$$\widetilde{\pi}_t = \beta_1\tilde{\pi}_{t+1} - \kappa\tilde{X}_t \tag{2.62}$$

$$\begin{aligned}\widetilde{q}_{h,t} &= \widetilde{C}_{2,t} - \beta_2\widetilde{C}_{2,t+1} + [\beta_2 + m(\beta_1 - \beta_2)]\,\widetilde{q}_{t+1} \\ &+ [m(\beta_1 - \beta_2)]\,(\widetilde{M}_t + \widetilde{\lambda}_{c,t} + \widetilde{\pi}_{t+1}) + [1 - (\beta_2 + m(\beta_1 - \beta_2))]\,(\widetilde{d}_t - \widetilde{h}_{2,t})\end{aligned} \tag{2.63}$$

$$\widetilde{q}_{h,t} = \widetilde{C}_{1,t} - \beta_1\widetilde{C}_{1,t+1} + \beta_1\widetilde{q}_{t+1} + [(1-\beta_1)]\,(\widetilde{d}_t + h_2h_1\widetilde{h}_{2,t}) \tag{2.64}$$

$$\widetilde{d}_t = \rho_d\widetilde{d}_{t-1} + \widetilde{\epsilon}_{d,t} + \widetilde{\epsilon}_{d,t-8} \tag{2.65}$$

$$\widetilde{M}_t = \rho_M\widetilde{M}_{t-1} + \widetilde{\epsilon}_{M_t} + \widetilde{\epsilon}_{M,t-8} \tag{2.66}$$

$$\frac{\widetilde{U_{h,l}}}{\widetilde{U_{c,l}}} = q_{h,t} - \frac{\beta_1}{1-\beta_1}(\widetilde{q}_{h,t+1} - \widetilde{q}_{h,t}) + \frac{\beta_1}{1-\beta_1}(\widetilde{R}_t - \widetilde{\pi}_{t+1}) \tag{2.67}$$

$$\begin{aligned}\frac{\widetilde{U_{h,b}}}{\widetilde{U_{c,b}}} &= q_{h,t} - \frac{(\beta_2 + m(\beta_1 - \beta_2))}{1 - (\beta_2 + m(\beta_1 - \beta_2))}(\widetilde{q}_{h,t+1} - \widetilde{q}_{h,t}) \\ &+ \frac{\beta_1}{1 - (\beta_2 + m(\beta_1 - \beta_2))}(\widetilde{R}_t - \widetilde{\pi}_{t+1}) + \frac{(1-m)(\beta_1 - \beta_2)}{1 - (\beta_2 + m(\beta_1 - \beta_2))}\widetilde{\lambda}_{c,t} - \frac{m(\beta_1 - \beta_2)}{1 - (\beta_2 + m(\beta_1 - \beta_2))}\widetilde{M}_t\end{aligned} \tag{2.68}$$

Steady State Equations - Full Model

$$\pi = 1 \tag{2.69}$$

$$\beta_1 = \frac{1}{R} \tag{2.70}$$

$$\delta = \frac{I}{K} \tag{2.71}$$

$$\lambda_c = \frac{\beta_1 - \beta_2}{C_2} \tag{2.72}$$

$$\lambda_e = \frac{\beta_1 - \gamma}{C_3} \tag{2.73}$$

$$K = \frac{\gamma\mu}{(1-\gamma(1-\delta))X} Y \tag{2.74}$$

$$q = \frac{d_1}{(1-\beta_1)} \frac{C_1}{h_1} \tag{2.75}$$

$$q = \frac{d_2}{(1-\beta_2-(\beta_1-\beta_2)m_2)} \frac{C_2}{h_2} \tag{2.76}$$

$$q = \frac{\gamma\nu}{(1-\gamma-(\beta_1-\gamma)m_3)X} \frac{Y}{h_3} \tag{2.77}$$

$$w_1 L_1 = \alpha(1-\mu-\nu)\frac{Y}{X} \tag{2.78}$$

$$w_2 L_2 = (1-\alpha)(1-\mu-\nu)\frac{Y}{X} \tag{2.79}$$

$$b_2 = \beta_1 m_2 q h_2 \tag{2.80}$$

$$b_3 = \beta_1 m_3 (\phi_h q_h h_3 + \phi_k q_k (1-\delta) K) \tag{2.81}$$

$$C_3 = [\mu + \nu]\frac{Y}{X} - \delta K - \left(\frac{1-\beta_1}{\beta_1}\right) b_3 \tag{2.82}$$

$$C_2 = w_2 L_2 - \left(\frac{1-\beta_1}{\beta_1}\right) b_2 \tag{2.83}$$

$$C_1 = w_1 L_1 + \left(\frac{1-\beta_1}{\beta_1}\right)(b_2 + b_3) + \left(1 - \frac{1}{X}\right) Y \tag{2.84}$$

$$C_0 = C_1 + C_2 + C_3 \tag{2.85}$$

$$L_1 = \left(\frac{\alpha(1-\mu-\nu)}{X}\frac{Y}{C_1}\right)^{\frac{1}{\eta}} \tag{2.86}$$

$$L_1 = \left(\frac{(1-\alpha)(1-\mu-\nu)}{X}\frac{Y}{C_1}\right)^{\frac{1}{\eta}} \tag{2.87}$$

$$\kappa = \frac{(1-\theta)(1-\beta_1\theta)}{\theta} \tag{2.88}$$

$$\frac{K}{Y} = \frac{\gamma\mu}{(1-\gamma(1-\delta)-(\beta_1-\gamma)(1-\delta)\phi_k m_3)X} \tag{2.89}$$

$$\frac{qh_1}{Y} = \left(\frac{d_1}{(1-\beta_1)}\right)\left[\left(\alpha(1-\mu-\nu)+X-1\right)+(1-\beta_1)\left[\left(\frac{m_2d_2}{(1-\beta_2-(\beta_1-\beta_2)m_2+d_2(1-\beta_1)m_2)}\right)\right.\right.$$
$$\left.\left.\left((1-\alpha)(1-\mu-\nu)\right)+\left(\frac{m_3\phi_h\gamma\nu}{(1-\gamma-(\beta_1-\gamma)\phi_h m_3)}\right)+\left(\frac{m_3\phi_k\gamma\mu}{(1-\gamma(1-\delta)-(\beta_1-\gamma)(1-\delta)\phi_k m_3)}\right)\right]\right]\frac{1}{X} \tag{2.90}$$

$$\frac{qh_2}{Y} = \left(\frac{d_2}{(1-\beta_2-(\beta_1-\beta_2)m_2)+d_2(1-\beta_1)m_2}\right)\left((1-\alpha)(1-\mu-\nu)\frac{1}{X}\right) \tag{2.91}$$

$$\frac{qh_3}{Y} = \frac{\gamma\nu}{(1-\gamma-(\beta_1-\gamma)m_3)}\frac{1}{X} \tag{2.92}$$

$$\frac{C_1}{Y} = \left[\left(\alpha(1-\mu-\nu)+X-1\right)+(1-\beta_1)\left[\left(\frac{m_2d_2}{(1-\beta_2-(\beta_1-\beta_2)m_2+d_2(1-\beta_1)m_2)}\right)\right.\right.$$
$$\left.\left.\left((1-\alpha)(1-\mu-\nu)\right)+\left(\frac{m_3\phi_h\gamma\nu}{(1-\gamma-(\beta_1-\gamma)\phi_h m_3)}\right)+\left(\frac{m_3\phi_k\gamma\mu}{(1-\gamma(1-\delta)-(\beta_1-\gamma)(1-\delta)\phi_k m_3)}\right)\right]\right]\frac{1}{X} \tag{2.93}$$

$$\frac{C_2}{Y} = \left(\frac{(1-\beta_2-(\beta_1-\beta_2)m_2)}{(1-\beta_2-(\beta_1-\beta_2)m_2)+d_2(1-\beta_1)m_2}\right)\left((1-\alpha)(1-\mu-\nu)\frac{1}{X}\right) \tag{2.94}$$

$$\frac{C_3}{Y} = \Bigg[\mu + \nu - (\delta + (1-\beta_1)(1-\delta)\phi_k m_3)\left[\frac{\gamma\mu}{(1-\gamma-(\beta_1-\gamma)(1-\delta)m_3)}\right] \\ - (1-\beta_1)\left[\phi_h m_3\left(\frac{\gamma\nu}{(1-\gamma-(\beta_1-\gamma)m_3)}\right)\right]\Bigg]\frac{1}{X} \quad (2.95)$$

$$\frac{b_2}{Y} = \left(\frac{\beta_1 m_2 d_2}{(1-\beta_2-(\beta_1-\beta_2)m_2)+d_2(1-\beta_1)m_2}\right)\left((1-\alpha)(1-\mu-\nu)\frac{1}{X}\right) \quad (2.96)$$

$$\frac{b_3}{Y} = \beta_1 m_3\left(\frac{\phi_h\gamma\nu}{(1-\gamma-(\beta_1-\gamma)\phi_h m_3)}\frac{1}{X} + \frac{\gamma\mu\phi_k}{(1-\gamma(1-\delta)-(\beta_1-\gamma)(1-\delta)\phi_k m_3)X}\right) \quad (2.97)$$

$$\frac{I}{Y} = 1 - \frac{C_1}{Y} - \frac{C_2}{Y} - \frac{C_3}{Y} \quad (2.98)$$

$$\frac{h_3}{h_1} = \frac{\frac{qh_3}{Y}}{\frac{qh_1}{Y}}, \qquad \frac{h_2}{h_1} = \frac{\frac{qh_2}{Y}}{\frac{qh_1}{Y}} \quad (2.99)$$

Linearised Equations - Full Model

$$\widetilde{Y}_t = \frac{C_1}{Y}\widetilde{C}_{1,t} + \frac{C_2}{Y}\widetilde{C}_{2,t} + \frac{C_3}{Y}\widetilde{C}_{3,t} + \frac{I}{Y}\widetilde{I}_t \tag{2.100}$$

$$\widetilde{C}_{1,t} = \widetilde{C}_{1,t+1} + \widetilde{\pi}_{t+1} - \widetilde{R}_t \tag{2.101}$$

$$\beta_1\widetilde{C}_{2,t} = \beta_2\widetilde{\pi}_{t+1} + \beta_2\widetilde{C}_{2,t+1} - (\beta_1 - \beta_2)\widetilde{\lambda}_{c,t} - \beta_1\widetilde{R}_t \tag{2.102}$$

$$\beta_1\widetilde{C}_{3,t} = \gamma\widetilde{\pi}_{t+1} + \gamma\widetilde{C}_{3,t+1} - (\beta_1 - \gamma)\widetilde{\lambda}_{e,t} - \beta_1\widetilde{R}_t \tag{2.103}$$

$$\widetilde{q}_{k,t} = \psi_k(\widetilde{I}_t - \widetilde{K}_{t-1}) \tag{2.104}$$

$$-\widetilde{h}_{1,t} = \frac{h_2}{h_1}\widetilde{h}_{2,t} + \frac{h_3}{h_1}\widetilde{h}_{3,t} \tag{2.105}$$

$$\widetilde{b}_{2,t} = \widetilde{M}_{2,t} + \widetilde{q}_{t+1} + \widetilde{\pi}_{t+1} + \widetilde{h}_{2,t} - \widetilde{R}_t \tag{2.106}$$

$$\begin{aligned}\widetilde{b}_{3,t} &= \widetilde{M}_{3,t} + \widetilde{\pi}_{t+1} - \widetilde{R}_t + \left[\frac{m_3\phi_h}{R}\frac{q_h h_3}{Y}\frac{Y}{b_3}\right](\widetilde{q}_{h,t+1} + \widetilde{h}_{3,t}) \\ &\quad + \left[1 - \frac{m_3\phi_h}{R}\frac{q_h h_3}{Y}\frac{Y}{b_3}\right](\widetilde{q}_{k,t+1} + \tilde{K}_t)\end{aligned} \tag{2.107}$$

$$\widetilde{Y}_t = \widetilde{A}_t + \mu\widetilde{K}_{t-1} + \nu\widetilde{h}_{3,t-1} + \alpha(1-\mu-\nu)\widetilde{L}_{1,t} + (1-\alpha)(1-\mu-\nu)\widetilde{L}_{2,t} \tag{2.108}$$

$$\widetilde{Y}_t = \widetilde{C}_{1,t} + \eta\widetilde{L}_{1,t} + \widetilde{X}_t \tag{2.109}$$

$$\widetilde{Y}_t = \widetilde{C}_{2,t} + \eta\widetilde{L}_{2,t} + \widetilde{X}_t \tag{2.110}$$

$$\widetilde{K} = \delta\widetilde{I}_t + (1-\delta)\widetilde{K}_{t-1} \tag{2.111}$$

$$\begin{aligned}\frac{b_2}{Y}\widetilde{b}_{2,t} &= \frac{C_2}{Y}\widetilde{C}_{2,t} + \frac{h_2 q}{Y}(\widetilde{h}_{2,t} - \widetilde{h}_{2,t-1}) + \frac{Rb_2}{Y}(\widetilde{R}_{t-1} - \widetilde{\pi}_t + \widetilde{b}_{2,t-1}) \\ &\quad + \left[(1-\alpha)(1-\mu-\nu)\frac{1}{X}\right](\widetilde{Y}_t - \widetilde{X}_t)\end{aligned} \tag{2.112}$$

$$\widetilde{R}_t = r_R\widetilde{R}_{t-1} + (1+r_\pi)(1-r_R)\widetilde{\pi}_{t-1} + r_Y(1-r_R)\widetilde{Y}_{t-1} + \widetilde{e}_{R,t} \tag{2.113}$$

$$\widetilde{\pi}_t = \beta_1\tilde{\pi}_{t+1} - \kappa\tilde{X}_t \tag{2.114}$$

$$\widetilde{C}_{0,t} = \frac{Y}{C_0}\widetilde{Y}_t - \frac{Y}{C_0}\frac{I}{Y}\widetilde{I}_t \tag{2.115}$$

$$\widetilde{L}_{0,t} = \frac{l_1}{l_0}\widetilde{L}_{1,t} + \frac{l_2}{l_0}\widetilde{L}_{2,t} \tag{2.116}$$

$$\widetilde{d}_t = \rho_d\widetilde{d}_{t-1} + \widetilde{\epsilon}_{d,t} \tag{2.117}$$

$$\widetilde{A}_t = \rho_A\widetilde{A}_{t-1} + \widetilde{\epsilon}_{A,t} \tag{2.118}$$

$$\widetilde{M}_t = \rho_M\widetilde{M}_{t-1} + \widetilde{\epsilon}_{M_t} \tag{2.119}$$

$$
\begin{aligned}
\frac{b_3}{Y}\widetilde{b}_{3,t} &= \frac{C_3}{Y}\widetilde{C}_{3,t} + \frac{Rb_3}{Y}(\widetilde{R}_{t-1} - \widetilde{\pi}_t + \widetilde{b}_{3,t-1}) + \frac{I}{Y}\widetilde{I}_t + \frac{h_3 q}{Y}(\widetilde{h}_{3,t} - \widetilde{h}_{3,t-1}) \\
&\quad + \left[(1-\alpha)(1-\mu-\nu)\frac{1}{X} + \alpha(1-\mu-\nu)\frac{1}{X} - \frac{1}{X}\right](\widetilde{Y}_t - \widetilde{X}_t)
\end{aligned} \tag{2.120}
$$

$$
\begin{aligned}
\widetilde{q}_{h,t} &= \widetilde{C}_{3,t} - \widetilde{C}_{3,t+1} + [1-\gamma-(\beta_1-\gamma)\phi_h m_3]\,(\widetilde{Y}_{t+1} - \widetilde{X}_{t+1} - \widetilde{h}_{3,t}) + [\gamma + m_3\phi_h(\beta_1-\gamma)]\,\widetilde{q}_{t+1} \\
&\quad + [(\beta_1-\gamma)\phi_h m_3]\,(\widetilde{M}_{3,t} + \widetilde{\lambda}_{e,t} + \widetilde{\pi}_{t+1} + \widetilde{C}_{3,t+1}) + \gamma\psi_h(\widetilde{h}_{3,t+1} - \widetilde{h}_{3,t}) - \psi_h(\widetilde{h}_{3,t} - \widetilde{h}_{3,t-1})
\end{aligned} \tag{2.121}
$$

$$
\begin{aligned}
\widetilde{q}_{h,t} &= \widetilde{C}_{2,t} - \beta_2\widetilde{C}_{2,t+1} + [\beta_2 + m_2(\beta_1-\beta_2)]\,\widetilde{q}_{t+1} + [m_2(\beta_1-\beta_2)]\,(\widetilde{M}_{2,t} + \widetilde{\lambda}_{c,t} + \widetilde{\pi}_{t+1}) \\
&\quad + [1-(\beta_2 + m_2(\beta_1-\beta_2))]\,(\widetilde{d}_t - \widetilde{h}_{2,t}) + [\beta_2\psi_h]\,(\widetilde{h}_{2,t+1} - \widetilde{h}_{2,t}) - \psi_h(\widetilde{h}_{2,t} - \widetilde{h}_{2,t-1})
\end{aligned} \tag{2.122}
$$

$$
\widetilde{q}_{h,t} = \widetilde{C}_{1,t} - \beta_1\widetilde{C}_{1,t+1} + \beta_1\widetilde{q}_{t+1} + [(1-\beta_1)]\,(\widetilde{d}_t - \widetilde{h}_{1,t}) + \beta_1\psi_h(\widetilde{h}_{1,t+1} - \widetilde{h}_{1,t}) - \psi_h(\widetilde{h}_{1,t} - \widetilde{h}_{1,t-1}) \tag{2.123}
$$

$$
\begin{aligned}
\widetilde{q}_{k,t} &= \widetilde{C}_{3,t} - \widetilde{C}_{3,t+1} + [\gamma(1-\delta) + (\beta_1-\gamma)(1-\delta)\phi_k m_3]\widetilde{q}_{k,t+1} \\
&\quad + [(\beta_1-\gamma)(1-\delta)\phi_k m_3](\widetilde{M}_{3,t} + \widetilde{\pi}_{t+1} + \widetilde{\lambda}_{e,t} + \widetilde{C}_{3,t+1}) \\
&\quad + [1-\gamma(1-\delta)-(\beta_1-\gamma)(1-\delta)\phi_k m_3](\widetilde{Y}_{t+1} - \widetilde{X}_{t+1} - \widetilde{K}_t) + \gamma\psi_k(\widetilde{I}_{t+1} - \widetilde{K}_t)
\end{aligned} \tag{2.124}
$$

Table 2.4: Full Model Calibrated Parameter Values

Parameter	Description	Value	Source
β_1	Patient HH discount factor	0.99	Iacoviello (2005)
β_2	Impatient HH discount factor	0.98	Iacoviello (2005)
γ	Entrepreneur discount factor	0.95	Iacoviello (2005)
δ	Capital depreciation rate	0.03	Iacoviello (2005)
ψ_k	Capital adjustment costs	2	Iacoviello (2005)
ψ_h	Housing adjustment costs	0	Iacoviello (2005)
μ	Capital share in production	0.3	Iacoviello (2005)
ν	Housing share in production	0.03	Iacoviello (2005)
α	Patient HH labour share	0.5	Kanik and Xiao (2014)
d	Weight on housing in utility function	0.1	Iacoviello (2005)
η	Frisch elasticity of labour supply	1.01	Kanik and Xiao (2014)
θ	Calvo stickiness	0.75	Kanik and Xiao (2014)
ϕ_π	Reaction coefficient on inflation	0.27	Kanik and Xiao (2014)
ϕ_y	Reaction coefficient on output	0.13	Kanik and Xiao (2014)
ϕ_r	Interest rate inertia	0.73	Kanik and Xiao (2014)
ρ_D	Autocorrelation of housing preference shock	0.85	Kanik and Xiao (2014)
ρ_M	Autocorrelation of collateral constraint shock	0.85	-
ϕ_h	Pledgability constraint on housing	$\{0.9, 0.5, 0.25, 0.1\}$	-
ϕ_k	Pledgability constraint on capital	$\{0.9, 0.5, 0.25, 0.1\}$	-
X	Steady state mark-up	1.05	Kanik and Xiao (2014)
r	Steady state interest rate	1.0101 $(1/\beta_1)$	Iacoviello (2005)

Table 2.5: Full Model Steady State Values v Data

Parameter	Description	Model SS	Data
c/y	Ratio of consumption to GDP	0.81	0.68
i/y	Ratio of investment to GDP	0.19	0.17
k/y	Ratio of capital stock to GDP	6.54	3.19
b/y	Ratio fo loans to GDP	7.01	1.72
$\frac{q_h h_1 + q_h h_2}{q_h h_3}$	Ratio of value of household real estate to entrepreneur real estate	1.41	1.58

Table 2.6: Model Performance: Standard Deviations and Cross Correlations

Variable	*SD%*					**Benchmark Model**				
	σ_y/σ_x	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)
Output	1	0.29	0.37	0.48	0.66	1	0.66	0.48	0.37	0.29
Consumption	1.18	0.33	0.40	0.51	0.68	0.99	0.68	0.51	0.40	0.33
Investment	0.38	-0.18	-0.16	-0.09	0.12	0.72	0.12	-0.09	-0.16	-0.18
House Prices	1.35	0.42	0.46	0.51	0.58	0.71	0.58	0.51	0.46	0.42
Business Credit	7.50	0.33	0.39	0.47	0.59	0.77	0.59	0.47	0.39	0.33
						Data				
	σ_y/σ_x	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)
Output	1	0.06	0.08	0.23	0.91	1	0.36	0.23	0.08	0.06
Consumption	0.75	0.31	0.51	0.69	0.84	0.91	0.86	0.74	0.57	0.40
Investment	5.30	0.41	0.55	0.71	0.85	0.93	0.83	0.63	0.39	0.17
House Price	5.41	0.45	0.54	0.63	0.66	0.65	0.56	0.44	0.34	0.30
Business Credit	1.62	-0.32	-0.31	-0.20	-0.05	0.11	0.11	0.17	0.29	0.40

All variables have been deflated using the implicit price deflator (IPD), logged and first differenced. Standard deviations have been normalised for GDP.

Appendix C - Selected Impulse Responses

Figure 2.10: News Shocks: LTV

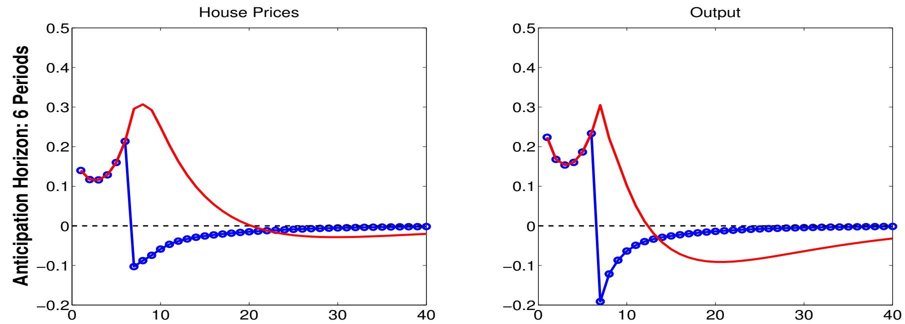


Figure 2.11: News Shocks: LTV

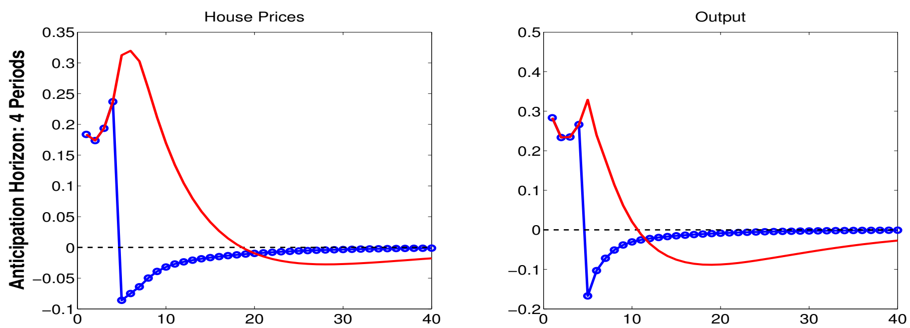


Figure 2.12: News Shocks: LTV

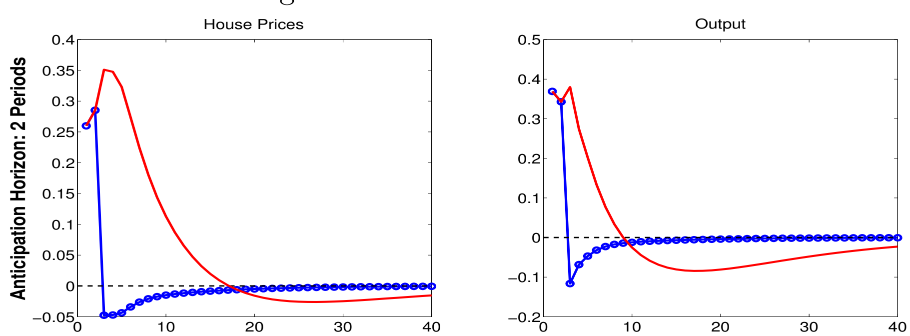
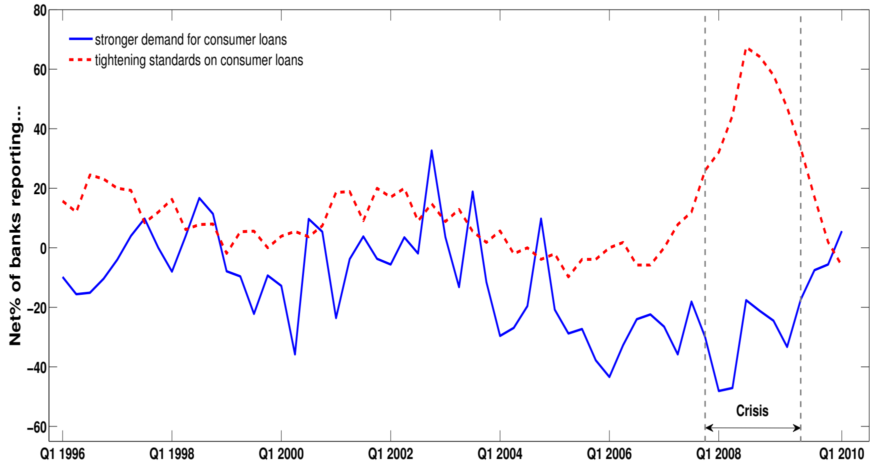


Figure 2.13: Consumer Loans: Tightness and Demand



Chapter 3

Macro-prudential Policy in a DSGE Model with Banking

3.1 Introduction

Estimates of the cost of the financial crisis for the U.S. economy in terms of lost output range from 40% to 90%; while household net worth fell by 24% and incalculable costs will also be borne by those whose skills have atrophied over the same period. Due to the severity of the financial crisis, the last decade has seen researchers focus their attention on ways in which similar crises can be both predicted, and their negative effects mitigated. Efforts to construct macro-prudential policy to help improve the stability of both national and international financial systems has been the mandate of newly instituted bodies set-up within existing policy institutions - namely, the Financial Stability Board, the Financial Policy Committee at the Bank of England and, more recently, the Division of Financial Stability at the FED.

Considerable effort has been expended in developing early warning systems (EWSs) that attempt to quantify the near-term likelihood of financial instability. Pre-crisis studies indicated that the most important leading indictors for financial crises were real GDP growth and changes in the terms of trade (Davis and Karim, 2008). When extending the analysis with a focus on OECD countries, Barrell et al. (2010) found that there is significant information content in the growth in property prices alongside other financial variables. In a comprehensive historical treatment of past crises, Jorda et al. (2013) show that developments in lagged credit growth perform well in indicating the likelihood of an impending crisis. However, Drehmann et al. (2012) show that broad credit supplemented with the growth of asset prices in terms of property yields an improvement over using broad credit as a stand alone metric.[1] Academic economists and practitioners are in wide agreement that developments in both the housing market and credit market, with their inherent feedback mechanisms, carry important information about financial stability that ought to provide direction for the construction of macro-prudential policy measures.

In developing policies designed to improve the stability of the financial system with the aim of reducing the severity of future crises, macro-prudential measures have been introduced in number of countries. Internationally, 27 member jurisdictions of the Basel Committee on Banking Supervision have implemented the Basel III reforms pertaining to risk-based capital ratios and the Liquidity Coverage Ratio (LCR). Some sovereign states have gone further in imposing macro-prudential regulatory reform on their domestic financial institutions. Hong Kong, Brazil, Korea and, more recently, the U.K., have each tightened up mortgage lending by introducing regulatory limits on either loan-to-value (LTV), loan-to-income (LTI) or debt-service-to-income (DTI) ratios on bank balance sheets with varying success (Jacome and Mitra, 2015).

[1] Throughout the EWS literature there is an implicit and erroneous assumption made: that because some variables historically carry predictive power for financial crises policymakers implementing tools that dampen the movements and these variables can by extension mitigate crises themselves. This assumes that these variables cause rather than merely correlate with episodic financial distress. An obvious criticism of this view is that that policy could reduce the number of variables that act as leading indicators rather than reduce the likelihood of a crisis itself. In order to examine the extent to which policy could, acting through these predictor variables, limit the harmful effects of a crisis requires a fully structural model.

The existing literature which introduces macro-prudential policy in DSGE models tends to take one of three general forms; firstly, a standard Taylor rule is augmented by the inclusion of additional variables that it is supposed are crucial leading indicators for financial distress; secondly, a separate entity following an *ad hoc* policy rule governing maximum loan-to-value (LTV) limits is added to the model; and thirdly, through the inclusion of an *ad hoc* rule for counter-cyclical capital requirements (CCR). The inclusion of the second form follows from the classification of household balance sheets as *indirect* threats to financial stability. The justification for the inclusion of macro-prudential policy in the third form is that highly levered bank balance sheets can act as a *direct* threat to financial stability.[2]

Much of the existing *'leaning against the wind'* (LATW) literature focuses on the reduction of the variances of output and inflation resulting from macro-prudential policy relative to a benchmark model by augmenting the Taylor Rule and simulating over various a range of theoretical values for the reaction coefficients. Linearised augmented Taylor Rules in the literature typically take the form;

$$\tilde{r}_t = r_r \tilde{r}_{t-1} + (1 - r_r)((1 + r_\pi)\tilde{\pi}_t - r_x \tilde{X}_t + \phi^\nu \Xi_t) + \epsilon_{r,t}$$

where ϕ^ν determines the response of policy rate to a deviation in the proxy for financial stability, variable Ξ_t. The evidence on the efficacy of augmented Taylor Rules of the form above, in which policy rate responds to deviations in an *ad hoc* range of financial variables, is somewhat mixed. In a model with financial intermediation, Gambacorta and Signoretti (2014) demonstrated that the inclusion of asset prices in the Taylor Rule does reduce the variability of both output and inflation bringing gains of between 20%-30%. However, the policy rule is only an effective improvement when the model is buffeted by supply-side shocks. Importantly, the model does not contain credit

[2] Interested readers are directed to BoE (2011) and BoE (2014)

constrained households and capital is the sole collateralisable asset. The results indicated that policy responding to changes in the price of capital has an important transmission through the wholesale banking unit via an increase in marginal costs that serve to dampen credit demand by the entrepreneur. Alternatively, Iacoviello (2005) specifies a Taylor Rule augmented by the inclusion of house prices. There was no improvement in the variability of inflation and a very marginal improvement in the variability of output.

The second class of models typically introduce a macro-prudential policy in the following form;

$$LTV_t = (-)\phi^{\nu}\Xi_t + \rho_{LTV}LTV_{t-1}$$

where ϕ^{ν} determines the response of the LTV ratio to a deviation in variable Ξ_t, typically to growth of broad credit, output or house prices. The evidence from the second class of models, in which macro-prudential policy is in the form of LTV limits imposed by the macro-prudential authority, is also mixed. Using debt-to-income (DTI) ratios as a proxy for financial distress, Chen and Columba (2016) estimate a model for the economy of Sweden and examine whether standard monetary policy or macro-prudential policy in the form of LTV limits is more successful in reducing said ratio. The authors find that macro-prudential policy dominates monetary policy as adjusting LTV ratios has an immediate impact on debt levels whereas monetary policy impacts debt as a second round effect. In a simulated model omitting both capital and financial intermediation, Rubio and Carrasco-Gallego (2013) find that anchoring macro-prudential policy to deviations in output and house prices unambiguously improves the joint welfare of agents. However, the improvement in the variability of both output and inflation are shock dependent with a technology shock reducing the variance of output whilst increasing the variance of inflation relative to the benchmark.

The final class model macro-prudential policy by anchoring capital requirements to financial variables and typically takes the form;

$$CCR_t = \phi^{\nu}\Xi_t + \rho_{CRR}CRR_{t-1}$$

where ϕ^{ν} determines the response of CCR to a deviation in variable Ξ_t, typically, as above, to growth of broad credit, output or house prices. In a model allowing for a rich set of nominal and real frictions, Gambacorta and Karmakar (2016) specify macro-prudential policy as an exogenous time-varying capital requirement anchored to deviations of the loan-to-output ratio from its steady state level. The authors find that when the model is subjected to a technology shock and macro-prudential policy is in operation the variability of output declines by between 24% and 28%. However, this comes at the cost of a steady state level of output being between 0.7% and 1.7% lower than in the absence of said policy. Ferreira and Nakane (2015) analyse the welfare gains from utilising a variety of variables as the anchor for macro-prudential policy and estimate this for the economy of Brazil. Their results indicated that the only variable that delivered welfare gains was growth in broad credit, with the gains themselves varying amongst agents: borrowers were found to be better off in consumption terms when macro-prudential policy supplemented monetary policy; whereas savers preferred a state of the world in which only monetary policy operated.

This paper introduces macro-prudential policy into a medium scale DSGE model with nominal and real frictions in order to answer three questions. Firstly, in a model where housing and capital are collateral assets, does the introduction of the CCR anchored to house price growth reduce the variability of output, inflation and aggregate borrowing[3]. Secondly, does the introduction of the macro-prudential body offer an improvement in terms of the variance of output, inflation and borrowing over a Taylor Rule following the *'lean against the wind'* principle. And thirdly, if

[3]Aggregate borrowing being taken as a proxy here for a financial stability measure. The results are qualitatively invariant to whether a measure of aggregate borrowing or the loans/GDP ratio is used.

macro-prudential policy is successful in terms of reducing the variance of output and inflation, are the results robust over a variety of shocks. In answering these questions, three alternate policy mandates are considered: first, the central bank minimises a loss function in terms of macro- and financial-stability;[4] second, the central bank minimise a loss function in terms of macro-stability, and a regulator minimises a loss function in terms of financial-stability;[5] and third, the central bank minimises a loss function in terms of macro-stability, and a regulator minimises in terms of macro- and macro-financial stability.[6]

[4] $L_{CB} = \alpha(varY_t) + var\pi_t + \beta(varB_t)$

[5] $L_{CB} = \alpha(varY_t) + var\pi_t \qquad L_{reg} = \beta(varB_t)$

[6] $L_{CB} = \alpha(varY_t) + var\pi_t \qquad L_{reg} = \alpha(varY_t) + \beta(varB_t)$

3.2 Model

The model follows a similar framework to Iacoviello (2005) and Gambacorta and Signoretti (2014). The economy is populated by patient and impatient households. They are differentiated by their discount factors, resulting in steady state borrowing for the impatient household[7]. The model also contains entrepreneurs who utilise housing assets, capital and labour from both households in order to produce a homogenous good. Impatient households are able to borrow against the value of housing assets; whereas entrepreneurs are able to borrow against both housing and capital assets (Liu et al., 2013).

The banking sector follows Gerali et al. (2010), but with the omission of perfect interest rate pass-through. We assume that there exist both perfectly competitive wholesale banks and monopolistically competitive retail banks, the latter subdivided into loan and deposit branches. Wholesale banks lend to retail branches by gathering deposits from patient households or using bank capital. Therefore, the framework allows from an analysis of macro-prudential policies that affect capital-to-asset requirements and transmit through this to credit prices and quantities in terms of interest rates and loan supply.

The model also contains both a monetary policy authority that sets the policy rate, and a macro-prudential authority that determines exogenously the target capital-to-asset requirement. A monopolistically competitive retail sector is included and, as is common elsewhere in the New-Keynesian literature, retailers acquire homogenous goods produced by entrepreneurs, differentiate them and retail them at a marked up price and can suffer further adjustment costs.

3.2.1 Households

The patient household maximises the following;

[7] A micro-founded justification for differing discount factors can be found in Liu et al. (2009).

$$E_0 \sum_{t=0}^{\infty} \beta_1^t \left((1-\gamma)\ln(C_{1,t} - \gamma C_{1,t-1}) + \Omega_t \ln h_{1,t} - \frac{L_{1,t}^{1+\phi}}{1+\phi} \right) \tag{3.1}$$

where utility depends on present and past consumption, the patient households holdings on the housing asset and labour hours worked by the patient household. The multiplicative term $(1-\gamma)$ ensures that the steady state is unaffected by the inclusion of consumption habits. The term Ω_t is a shock to the marginal rate of substitution of housing against consumption and leisure[8]. The households maximisation problem is subject to the following flow budget constraint;

$$C_{1,t} + D_t + q_t^h h_{1,t} \leq w_{1,t} L_{1,t} + (1 + r_{t-1}^d) D_{t-1} + q_t^h h_{1,t-1} + J_t^R + (1-\omega) J_{t-1}^B \tag{3.2}$$

where q_t^h is the price of housing. Household income flowing from employment, returns on previous periods deposits, value of last periods housing stock, retailers and banking sector profits is equal to or less than the households expenditure on consumption goods, present period housing asset purchases and present period deposits. The patient households problem is to maximise utility by choosing consumption (C_1), housing assets (h_1), labour supply (L_1) and deposits (D) subject to equation (3.2).

The impatient households problem is broadly similar;

$$E_0 \sum_{t=0}^{\infty} \beta_2^t \left((1-\gamma)\ln(C_{2,t} - \gamma C_{2,t-1}) + \Omega_t \ln h_{2,t} - \frac{L_{2,t}^{1+\phi}}{1+\phi} \right) \tag{3.3}$$

where the subscripts $\{1, 2\}$ indicate the variables pertaining to the patient and impatient households, respectively. The impatient households maximisation problem is subject to a flow budget

[8] We can think of this as an exogenous increase in utility gained from housing services over that derived from consumption and leisure.

constraint similar to that of the patient household;

$$C_{2,t} + (1 + r^{bh}_{t-1})b^h_{t-1} + q^h_t h_{2,t} \leq w_{2,t} L_{2,t} + b^h_t + q^h_t h_{2,t-1} \tag{3.4}$$

where b^h is impatient household borrowing. However, the impatient household is constrained in their borrowing by the value of their housing assets. Therefore, the flow budget constraint is supplemented with the following borrowing constraint;

$$(1 + r^{bh}_t)b^h_t \leq \left(m^h_t q^h_{t+1} h_{2,t} \pi_{t+1}\right) \tag{3.5}$$

where the parameter m^h measures loan-to-value constraint imposed on the household and π is inflation. Therefore, the impatient households problem is to maximise utility by choosing consumption (C_2), housing assets (h_2), labour supply (L_2) and borrowing (b^h) subject to equations (3.4) and (3.5). Notice that the impatient household has two uses for the housing asset: first, the utility gained from the flow of housing services; second, the value of housing as a collateralisable asset that enables higher levels of borrowing.

3.2.2 Entrepreneur

The entrepreneur maximises the following;

$$E_0 \sum_{t=0}^{\infty} \beta^t_3 \left[(1 - \gamma) \ln(C_{3,t} - \gamma C_{3,t-1})\right] \tag{3.6}$$

where C_3 denotes entrepreneurial consumption and, as is common with the above household problems, γ is the habit persistence parameter. The entrepreneur chooses the level of capital, commercial real estate, patient households labour and impatient households labour in order to produce an intermediate good denotes Y_t. Therefore, the production function governing the intermediate good is given as;

$$Y_t = A_t(K_{t-1})^{\mu} h_{3,t-1}^{\eta} L_{1,t}^{\alpha(1-\mu-\eta)} L_{2,t}^{(1-\alpha)(1-\mu-\eta)} \tag{3.7}$$

where A is a transitory technology shock, K the level of capital stock, h_3 the entrepreneurs holding of the housing asset, L_1 patient household labour supply and L_2 impatient household labour supply. The law of motion for capital follows;

$$K_t = (1-\delta^k)K_{t-1} + \left[1 - \frac{\kappa_i}{2}\left(\frac{I_t}{I_{t-1}} - 1\right)^2\right] I_t \tag{3.8}$$

where I is investment and κ_i is the adjustment cost parameter for investment. The entrepreneur also faces a binding borrowing constraint;

$$(1 + r_t^{be})b_t^e = \left(m_t^k q_{t+1}^k K_t(1-\delta^k)\pi_{t+1} + m_t^h q_{t+1}^h h_{3,t}\pi_{t+1}\right) \tag{3.9}$$

where q_k is the shadow price of capital and m_k is the loan-to-value constraint on capital. This form of collateral constraint follows Liu et al. (2013) and limits the quantity of credit a firm is able to access to some fraction of the value of their holdings of both housing and capital assets. The entrepreneur faces the following flow budget constraint;

$$C_{3,t} + (1 + r_{t-1}^{be})b_{t-1}^e + w_{1,t}L_{1,t} + w_{2,t}L_{2,t} + q_t^k K_t + q_t^h h_{3,t} \leq \frac{Y_t}{X_t} + b_t^e + q_t^k(1-\delta_k)K_{t-1} + q_t^h h_{3,t-1} \tag{3.10}$$

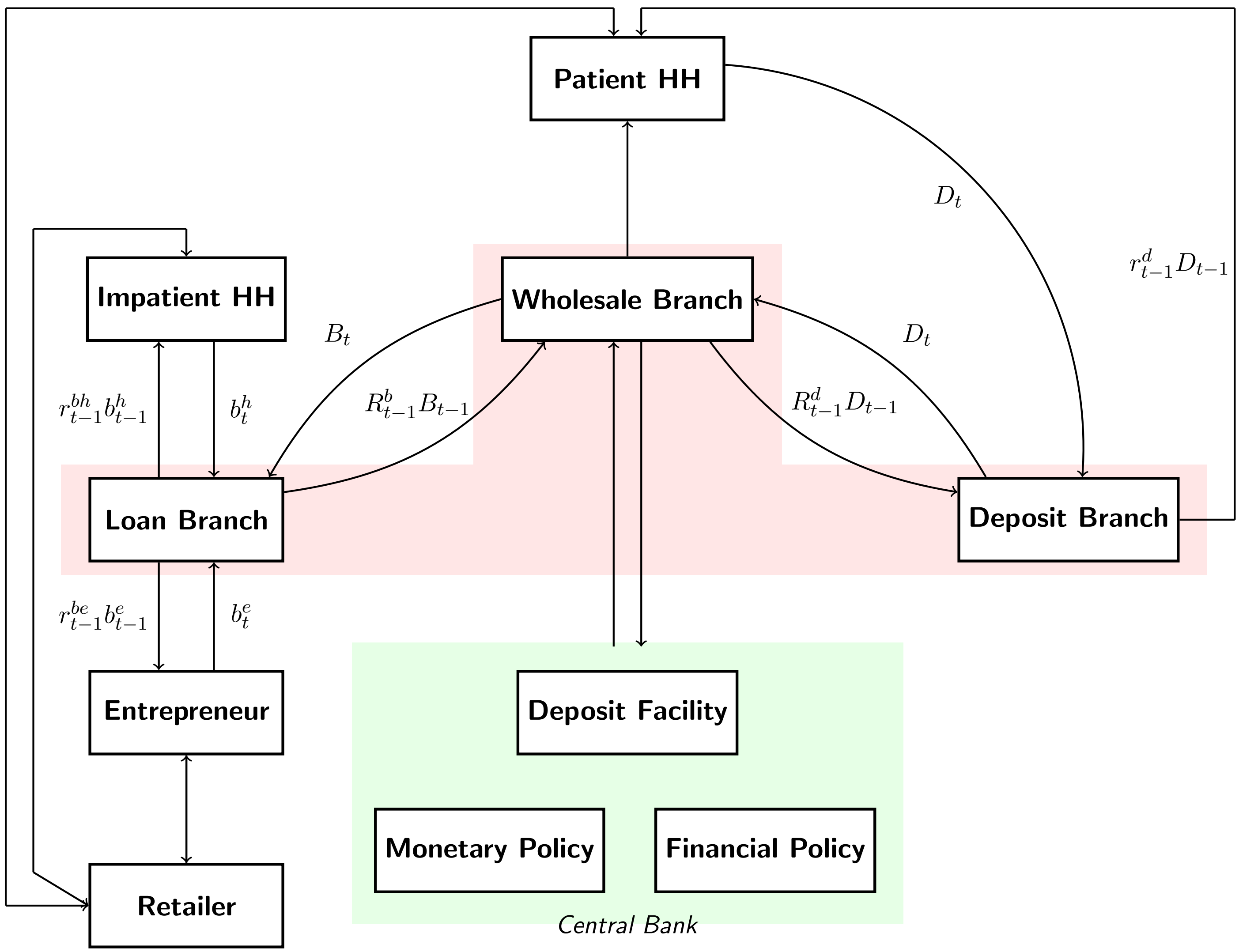
where the righthand side represents income and the lefthand side expenditure. Therefore, in order to maximise utility the entrepreneur chooses the level of consumption (C_3), capital (K), housing assets (h_3), patient and impatient household labour (L_1 & L_2), investment (I), and borrowing (b_e) subject to equations (3.7), (3.8), (3.9) and (3.10). The derivation of the price of capital follows Liu et al. (2013) and is contained in the entrepreneurs problem, although the resultant Tobin's q is equivalent to an explicit derivation found in models which incorporate a capital goods producer.

3.2.3 Banking Sector

Banks are constituted of two parts: the first is a perfectly competitive wholesale branch; the second a monopolistically competitive retail unit. The retail unit is sub-divided into a loan branch and a deposit branch. The deposit branch collects savings from patient households in the form of deposits (D), paying the rate r^d, and distributes these to the wholesale branch at rate R^d. The wholesale branch combines deposits and bank capital (K^b) and lends the resultant funds to the loan branch of the retail bank at rate R^b. The loan branch costlessly differentiates the borrowed funds (B) into impatient household loans (b^h) and loans to entrepreneurs (b^e) and lends these after applying two mark-ups: r^{bh} for the impatient households loans and r^{be} for loans to entrepreneurs. Excess funds held at the wholesale branch can used to purchase riskless bonds from the central bank at rate r.

Financial intermediation in this form introduces a number of interesting dynamics. The structure of the model allows for a macro-prudential regulator to be introduced that sets a required capital-asset ratio determined by changes in the economic environment. By specifying a macro-prudential policy rule governing the capital-asset ratio that responds to changes in certain variables, the regulator can influence the behaviour of lending institutions. Conceptually, this is equivalent to counter-cyclical capital requirements imposed under Basel III (BIS, 2011). Secondly, a bank capital shock can be introduced. This allows an examination of the efficacy of macro-prudential policy in the form of counter-cyclical capital requirements in response to a deterioration in assets. And thirdly, as equation (3.13) shows, there is transmission channel from bank profits - assuming a credit related anchor - to economic conditions (Chen and Columba, 2016).

Figure 3.1: Model with financial flows



Wholesale branch

The wholesale branch maximises the following;

$$E_0 \sum_{t=0}^{\infty} \beta_1 \left((1+R_t^b)B_t(j) - (1+R_t^d)D_t(j) - K_t^b(j) - \overbrace{\frac{\theta}{2}\left(\frac{K_t^b}{B_t} - \nu_t\right)^2 K_t^b(j)}^{\Psi} \right) \tag{3.11}$$

where ν is an exogenously determined ratio of bank capital to assets set by the macro-prudential authority; and the final term overbraced by Ψ is the cost, parameterised by θ, borne by the bank for deviating from the aforementioned capital-asset ratio. The wholesale branch maximisation problem is subject to the balance sheet identity;

$$B_t(j) = D_t(j) + K_t^b(j) \tag{3.12}$$

where, as mentioned above, B_t is total loanable funds transferred to the retail branch, D_t is deposits recieved from the deposit branch and K^b is bank capital. The law of motion for bank capital follows;

$$K_{t+1}^b(j) = (1-\delta^b)\frac{K_t^b(j)}{\epsilon_t^k} + J_t^b \tag{3.13}$$

where δ^b is effectively the depreciation rate of bank capital which proxies the cost the bank undertakes in conducting intermediation services it provides, and J^b is profits made by the banking sector. A bank capital shock, given by ϵ_t^k, follows an AR(1) process with the autocorrelation coefficient ρ_{Ek} and standard deviation σ_{Ek}.

Loan branch

Demand for loanable funds b^h and b^e is from the impatient households and entrepreneurs. Therefore, the loan branch maximises the following by choosing a monopolistically competitive mark-up over the wholesale lending rate on lending to each category of retail lending;

$$E_0 \sum_{t=0}^{\infty} \beta_1 \left(r_t^{bh}(j) b_t^h(j) + r_t^{be}(j) b_t^e(j) - R_t^b B_t(j) \right) \tag{3.14}$$

subject to the loan demand schedules;

$$b_t^h(j) = \left(\frac{r_t^{bh}(j)}{r_t^{bh}} \right)^{-\epsilon^{bh}} b_t^h \qquad b_t^e(j) = \left(\frac{r_t^{be}(j)}{r_t^{be}} \right)^{-\epsilon^{be}} b_t^e \tag{3.15}$$

where $\{\epsilon^{bh}, \epsilon^{be}\}$ are the relative elasticities of loan demand for impatient household and entrepreneur loans, respectively.

Deposit branch

The problem faced by the deposit branch is similar to that faced by the loan branch. The deposit branch collects deposits from patient households and maximises the following by choosing a monopolistically competitive mark-down on the deposit rate at which to lend deposited funds to the wholesale branch;

$$E_0 \sum_{t=0}^{\infty} \beta_1 \left(r_t^d D_t(j) - r_t^d(j) d_t(j) \right) \tag{3.16}$$

subject to;

$$d_t(j) = \left(\frac{r_t^d(j)}{r_t^d} \right)^{\epsilon^d} D_t \tag{3.17}$$

where ϵ^d is the elasticity of deposit demand. To finalise the sector, banking profits are stated as the sum of the profits for each branch;

$$J_t^B = r_t^b B_t - r_t^d D_t - \frac{\theta}{2}\left(\frac{K_t^b}{B_t} - \nu_t\right)^2 K_t^b \tag{3.18}$$

Retailers

The retailers problem follows the New-Keynesian literature in that retailers differentiate homogenous goods at no cost and retail these at a mark-up in the goods market. The retailers problem is;

$$\max_{\{P_t(i)\}} E_0 \sum_{t=0}^{\inf} \beta_1^t \left\{ P_t(j)y_t(j) - P_t^W y_t(j) + \frac{\kappa^p}{2}\left(\frac{P_t(j)}{P_{t-1}(j)} - 1\right)^2 P_t y_t \right\} \tag{3.19}$$

subject to the demand constraint;

$$y_t(j) = \left(\frac{P_t(j)}{P_t}\right)^{\epsilon^y} y_t \tag{3.20}$$

The first order condition of the retailer in symmetric equilibrium is;

$$1 - \epsilon_t^y + \epsilon_t^y \frac{1}{x} - \kappa^p(\pi_t - 1)\pi_t + \beta_1 E_t \left[\frac{\lambda_{t+1}^p}{\lambda_t^p}\kappa^p(\pi_{t+1} - 1)\pi_{t+1}\frac{y_{t+1}}{y_t}\right] = 0 \tag{3.21}$$

where κ^p measures adjustment costs of changing prices, ϵ_t^y is the elasticity of substitution faced by retailers and x is the mark-up imposed by retailers.

Monetary Policy

The monetary policy rule is standard and is of the form;

$$R_t = R_{t-1}^{r_r}\left[\pi_t^{1+r_\pi} X_t^{-r_x}\right]^{1-r} \epsilon_{r,t} \tag{3.22}$$

where r_r determines interest rate inertia, r_π determines the response of policy rate to changes in the rate of inflation with no lag, r_x is the response to the mark-up[9] and $\epsilon_{r,t}$ is a monetary policy shock following an AR(1) process with autocorrelation coefficient ρ_{er} and standard deviation σ_{er}.

Market Clearing and Aggregation

The remaining equations determine aggregate consumption, housing asset holdings, borrowing, and goods market equilibrium;

$$C_t = C_{1,t} + C_{2,t} + C_{3,t} \tag{3.23}$$

$$H_t = h_{1,t} + h_{2,t} + h_{3,t} \tag{3.24}$$

$$B_t = b_t^h + b_t^e \tag{3.25}$$

$$Y_t = C_t + q_{k,t}(K_t - (1-\delta^k)K_{t-1}) + \frac{\delta^b K_{t-1}^b}{\pi_t} \tag{3.26}$$

The competitive equilibrium is a sequence of prices $\{w_{1,t}, w_{2,t}, R_t, R_t^b, R_t^d, r_t^{be}, r_t^{bh}, r_t^d, q_t^k, q_{h,t}, P_t, X_t\}$ and allocations $\{C_{1,t}, C_{2,t}, C_{3,t}, h_{1,t}, h_{2,t}, h_{3,t}, L_{1,t}, L_{2,t}, I_t, K_t, K_t^b, Y_t, b_t^h, b_t^e, D_t, J^b, J_t^R\}_{t=0}^{\infty}$ such that, taking prices as they are, the allocation yields the solution to the agents' respective optimising problems and markets clear.

[9]The mark-up has an negative relationship with the policy rate as it represents inversely the standard output gap formation of the same policy rule. For a detailed explanation of this concept, see Gali (2008)

3.3 Estimation

The model is estimated using Bayesian methods for five quarterly U.S. time series data spanning 1975Q1 to 2015Q4. The observables are log real house price; log relative price of capital; log real consumption per capita; log real investment per capita; log gross real debt. Nominal variables have been deflated using the GDP deflator to obtain real value, and all series were filtered using the one-sided Hodrick-Prescott filter following Pfeifer (2017). Details of the treatment of the five U.S. time series, transformations and priors can be found in the appendices B and C below.

The structural model contains five shocks: technology (A_t); monetary policy (er_t); housing preference (Ω_t); bank capital quality (Ek_k); and loan-to-value (M_t).

3.3.1 Parameter values: calibration

As has been noted elsewhere in the literature, a number of parameters require calibration. This is due to their being notoriously difficult to pin down. As in Gerali et al. (2010), the patient households discount factor is determined by the average rate on M2 deposits over the sample period 1975:Q1 to 2015:Q4. The average rate on U.S. M2 was 3.269% allowed us to pin down the discount rate to 0.9918. Following Iacoviello and Neri (2010), the discount factors for both the impatient household and entrepreneur are set lower than that for patient households at 0.98 and 0.975, respectively. Parameters determining capital share, labour share and housing share are taken from Iacoviello (2005) and are 0.3, 0.64 and 0.03, respectively. The effective depreciation rate of bank capital - or cost of managing the banks capital balance sheet is taken from Gerali et al. (2010) set to 0.0059. The depreciation rate of physical capital is taken from Gambacorta and Signoretti (2014) and set at 0.05. The weight on housing in the utility function of both the patient and impatient household is equal and set at 0.2 following Gambacorta and Signoretti (2014). The steady state value for the target ratio of capital to assets is set to 0.09, again following Gerali et al. (2010). The goods market mark-up is assumed to be in the region of 15%, thus ϵ^y is set to 5. The loan-to-value ratio for household borrowing is set to 0.9 following Iacoviello (2015). Values concerning the ability of firms to borrow against capital are less well established and range from 0.1 (Ferreira and Nakane, 2015) to 0.3 (Christensen et al., 2007). Therefore, the value of 0.2 was chosen. The model assumes that the mark-up on household and entrepreneur borrowing is equal, implying $\epsilon^{bh} = \epsilon^{be}$ - this is set to 3 (Gambacorta and Signoretti, 2014); ϵ^d is taken from Gerali et al. (2010) and set at -1.5.

In the baseline estimation macro-prudential policy is switched off and an otherwise standard Taylor Rule is specified - i.e, the parameter ϕ^v is set to zero. One problem with this method is that the resultant posterior estimates are not invariant to an otherwise identical mode estimated with ϕ_v varying over defined parameter space used for counter-factual policy analysis. However, if ϕ_v were to be estimated and set to the posterior this would not allow for an examination of the efficacy of macro-prudential in reducing the variance of target variables over a theoretical range of values for the reaction coefficient.

3.3.2 Parameter values: priors and posterior estimates

Priors

Selection of prior means, standard deviation and prior shape follow loosely Gerali et al. (2010) and are detailed in Table 3.2 below. For the parameters determining the adjustment cost of prices, investment and bank capital, a gamma distribution is specified. The parameter determining adjustment costs of investment has a prior mean of 5 with a relatively loose standard deviation of 4. For adjustment costs of prices, a mean of 50 with a standard deviation of 20 was selected. The prior for the parameter governing the cost of a bank adjusting its capital is set with a mean of 10 and a

Table 3.1: Calibrated Parameter Values

Param	Description	Value	Source
β_1	Patient HH discount factor	0.99	Data
β_2	Impatient HH discount factor	0.98	Iacoviello and Neri (2010)
β_3	Entrepreneur discount factor	0.975	Iacoviello and Neri (2010)
δ_k	Depreciate rate of capital	0.05	Gambacorta and Signoretti (2014)
α	Patient labour share	0.64	Iacoviello (2005)
μ	Capital share	0.3	Iacoviello (2005)
ν	Housing share	0.03	Iacoviello (2005)
ω	Weight on housing in utility function	0.2	Gambacorta and Signoretti (2014)
η	Target capital-to-asset ratio	0.09	Gerali et al. (2010)
$\epsilon^b h, e$	Elasticity of sub across loans ($\frac{\epsilon^b}{\epsilon^b-1}$ mark-up)	3	Gambacorta and Signoretti (2014)
ϵ^d	Elasticity of sub across deposits ($\frac{\epsilon^d}{\epsilon^d-1}$ mark-down)	-1.5	Gerali et al. (2010)
ϵy	Elasticity of sub across goods ($\frac{\epsilon^y}{\epsilon^y-1}$ mark-up)	6	Gerali et al. (2010)
δ_b	Cost of managing banks capital position	0.059	Gerali et al. (2010)
m_h	LTV on housing asset	0.9	Iacoviello (2015)
m_k	LTV of capital	0.2	Literature average
ϕ_v	Macro-prudential coefficient	0	-

Note: where *'Literature'* is stated as the source of the calibrated value this indicates that said value sits mid-range within the existing literature in this field.

standard deviation of 2. Habit persistence for patient, impatient and entrepreneur consumption is assumed to have a mean of 0.5 with a standard deviation of 0.4.

For the parameters determining the inertia of interest rate setting and the policy response to deviations in both inflation and the mark-up, a gamma distribution is specified. The responsiveness of the policy rate to deviations in the contemporaneous rate of inflation has a prior mean of 2 with a standard deviation of 1. The degree of interest rate smoothing - or policy inertia - has a mean of 0.75 with a standard deviation of 0.05. The responsiveness of the policy rate to contemporaneous deviations in the mark-up is assumed to have a prior mean of 0.75 with a standard deviation of 0.05.

An inverse gamma distribution is selected for the parameters determining the autocorrelation coefficients for the shock processes, whilst a gamma distribution is selected for the standard deviation of the shocks. The autocorrelation coefficients are each assumed to have a prior mean of 0.5

with a standard deviation of 0.4. The standard deviation of shock processes are assumed to have a prior mean of 0.1 with a standard deviation of 2.

Posterior estimates

The posterior distributions are sampled by running ten parallel chains of 1,000,000 replications of the Metropolis Hastings algorithm. Convergence is checked by using the metrics provided by Brooks and Gelman (1998). Posterior estimates with the 10$^{\text{th}}$ & 90$^{\text{th}}$ percentiles are contained in Table 3.2 below.

The estimate for investment adjustment costs is noticeably lower than that in existing literature, with the exception of Gelain and Ilbas (2017). The estimated value for adjustment costs related to prices is also noticeably above usual values. However, as shown by Keen and Wang (2007), this is not outside plausible values.[10] The posterior estimate for bank capital adjustment costs is very similar to that found in Gerali et al. (2010), but is weakly identified. Estimates of habit persistence in models of this form vary somewhat owing to the parameter determining the persistence of consumption for a number of agents. The resultant figure, although seemingly low, is well within the bounds found in related literature (Gelain and Ilbas, 2017) (Liu et al., 2013). The estimated value for the coefficient on inflation in the policy rule implies very hawkish monetary policy. The results also indicate inert policy movements, with the interest rate smoothing parameter estimated to be 0.83. The coefficient on mark-ups in the goods market is standard, but weakly identified in the data.

The size of the shocks are relatively standard. The notable size of the preference shock is explicable as it ensures the relative variances match the data. Interestingly, the housing preference shock is also much less persistent. The shock to bank capital is also relatively large. Figures for

[10] Where $\kappa^p = \left[\frac{(1-\epsilon^y)\phi}{(1-\phi)(1-\beta_1\phi)}\right] \Longrightarrow 116.0136 = \left[\frac{(1-6)\phi}{(1-\phi)(1-0.9918\phi)}\right]$. Therefore, $\phi = 0.8$ implying that 80% will not be able to adjust their prices.

prior and posterior plots can be found in Figure 3.16 and Figure 3.17 below.

Table 3.2: Full Sample Estimates: 1975Q1 - 2015Q4

		Prior			Posterior		
Parameter	Description	Density	Mean	Std.dev.	Mean	10^{th}	90^{th}
κ_i	Investment adjustment cost	G	5.00	4.00	0.4889	0.3920	0.5834
κ_p	Price stickiness	G	50.00	20.00	116.8945	93.7184	139.7380
θ	Bank capital adjustment cost	G	10.00	2.00	9.9426	6.6253	13.1180
a^p	Habit formation patient HH	G	0.50	0.40	0.4581	0.4179	0.4979
a^i	Habit formation impatient HH	G	0.50	0.40	0.4581	0.4179	0.4979
a^e	Habit formation entrepreneur	G	0.50	0.40	0.4581	0.4179	0.4979
r_π	Taylor rule inflation	G	2.00	1.00	11.2103	8.4635	14.0197
r_r	Taylor rule smoothing	G	0.75	0.05	0.8360	0.7792	0.8938
r_x	Taylor rule mark-up	G	0.75	0.05	0.7362	0.6564	0.8166
σ_A	Std.Dev. TFP	IG	0.10	2.00	0.0297	0.0266	0.0327
σ_{er}	Std.Dev. Monetary policy	IG	0.10	2.00	0.0080	0.0050	0.0110
σ_Ω	Std.Dev. Housing Preference	IG	0.10	2.00	0.5216	0.4521	0.5906
σ_M	Std.Dev. LTV	IG	0.10	2.00	0.0078	0.0069	0.0087
σ_{Ek}	Std.Dev. Bank capital	IG	0.10	2.00	0.0304	0.0268	0.0340
ρ_A	AR(1) TFP	B	0.50	0.40	0.9805	0.9756	0.9854
ρ_{er}	AR(1) Monetary policy	B	0.50	0.40	0.9112	0.8768	0.9458
ρ_Ω	AR(1)Housing Preference	B	0.50	0.40	0.5848	0.5335	0.6358
ρ_M	AR(1) LTV	B	0.50	0.40	0.8672	0.8393	0.8955
ρ_{Ek}	AR(1) Bank capital	B	0.50	0.40	0.9549	0.9426	0.9675

Data and estimation files can be sent upon request.

3.4 Quantitative Results

With the exception of Gambacorta and Signoretti (2014) and Yu (2014), the existing literature anchors macro-prudential policy rules to either the credit-to-GDP gap or growth in different definitions of credit volumes. As has been shown by Kannan et al. (2012), macro-prudential policy anchored to credit growth can both increase or decrease welfare, dependent on the source of the shock. Where policy responds to broad credit growth after a housing preference shock, the addition of macro-prudential policy is welfare improving. However, if on receipt of a productivity shock policy acts to reduce credit this causes welfare to fall. It is common in the literature to use credit as a policy anchor due to its impact on asset prices spirals. However, in what follows house price growth is included in the macro-prudential rule explicitly rather than being affected indirectly through a tightening due to credit growth. This is for two reasons. Firstly, in a model where the collateral constraint always binds, a change in asset prices will lead directly to a change in credit. If the aim of policy is to tighten financial conditions in response to asset price movements, responding directly to the growth in house prices will ensure that the policy response is not excessive when a shock drives credit to a significantly larger degree than house prices, but will still act to constrain credit growth in response to house price growth. And secondly, a number of recent studies have shown that asset prices in the form of housing add significant predictive content to early warning systems that attempt to forecast near-term financial distress. As macro-prudential policy bodies are mandated to improve financial stability, using house prices in the macro-prudential rule is consistent with said mandate.

The paper has two central aims. First, to examine whether macro-prudential policy in the form of CCR anchored to house prices delivers gains when assessed against a number of differing central bank loss function specifications constituted of output, inflation and aggregate borrowing. And second, to examine whether this form of macro-prudential policy delivers significant improvements over a LATW policy in which the same variable is instead added to an otherwise standard Taylor Rule. Therefore, the results of the paper allow a re-assessment of Iacoviello (2005) on the ineffectual inclusion of the housing asset as a macro-prudential policy anchor, but examines whether this is due to the form in which macro-prudential policy takes. The benchmark model is estimated with a standard Taylor Rule and capital requirements determined exogenously. In order to conduct counter-factual policy experiments, the coefficient determining the response of capital requirements to house price growth, ϕ^{ν}, is varied and the theoretical moments are compared to those of the benchmark model simulated using the posterior estimates when macro-prudential policy is switched off. Once the impact of macro-prudential policy in the form of capital requirements has been examined relative to the benchmark model, ϕ^{ν} is set to zero and instead the Taylor Rule is augmented with house price growth and a similar experiment is carried out again relative to the benchmark model. The performance of the two forms of macro-prudential policy is after assessed by examining the implications on the loss function for three specifications of the the central bank's mandate. The first is a loss function constituted of output, inflation and aggregate borrowing, specified thus;

$$L_{CB} = \alpha(varY_t) + var\pi_t + \beta(varB_t)$$

.

where α is the weight on output stability and β is the weight on borrowing stability. In the second the central bank minimises a loss function in terms of macro-stability, and a regulator minimises a loss function in terms of financial-stability, specified thus;

$$L_{CB} = \alpha(varY_t) + var\pi_t \qquad L_{reg} = \beta(varB_t)$$

.

where L_{reg} indicates the loss function of the financial regulatory body. In the case of the third the central bank minimises a loss function in terms of macro-stability, and a regulator minimises in terms of macro- and macro-financial stability, specified thus;

$$L_{CB} = \alpha(varY_t) + var\pi_t \qquad L_{reg} = \alpha(varY_t) + \beta(varB_t)$$

.

When conducting policy experiments, two steps are taken. First, the model is simulated with the two separate types of policy both over a range for ϕ^{ν} between [0,10] in discrete jumps of 1. In each simulation, the theoretical moments are stored and normalised to the benchmark case where no policy is active. Second, the theoretical moments are then inputted into the relevant mandates described above. As the relevant metric by which we measure gains here are the alternate loss functions rather than welfare in terms of consumption units, the resultant gains or losses are assessed over the range [0,0.3], again in discrete jumps of 0.1, of values for the weight given to borrowing variability in the loss function. In all experiments carried out, α is fixed at 0.5 following the discussion in Carney (2017). Tables 3.6 and 3.5 below report the standard deviations for output, inflation and borrowing for each each type of shock and both sets of policies.

3.4.1 Technology Shock

Figure 3.2 plots the standard deviation of output, inflation and borrowing along with the mandates defined in each of the y-axes. In each case the model is simulated over the ϕ^{ν} space. As can be seen from Table 3.6, in response to a technology shock when CCR policy is active and $\phi^{\nu} = 5$ the standard deviation of output falls to a low of -7.38% relative to the benchmark model. However, the standard deviation of inflation and aggregate borrowing is increasing over the full range of ϕ^{ν}.

Interestingly, the trade-off between stabilising output and inflation is minimal - in order to reduce the variability of output by 7.28% the policymaker must accept an increase in the variability of inflation by 4.99%. However, the trade-off between decreasing the variability of output and aggregate borrowing is substantial: a 4% decline in output variability implies a 600% increase in borrowing variability. Due to the significant fluctuation in borrowing volumes under CCR, each mandate delivers substantial losses even given very small values of the weight in on borrowing in each loss function.[11]

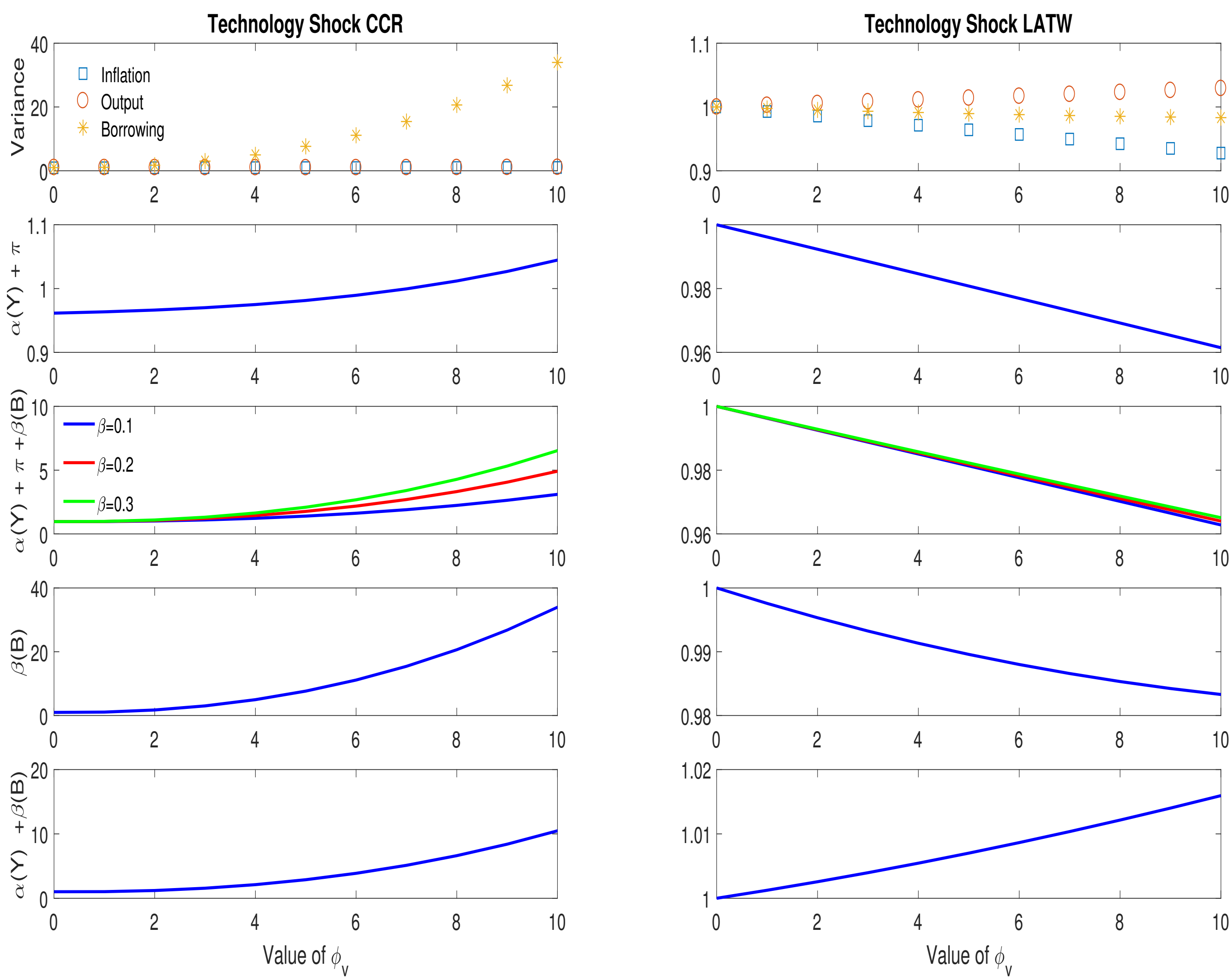
Table 3.5 in the appendix reports the results for output and inflation variability for shocks when an augmented Taylor Rule replaces the capital requirement tool used above. It can be seen that when policy takes this form it produces a significant trade-off in terms of output and inflation variability. With a higher variance of output when macro-prudential policy is conducted through the Taylor Rule, this somewhat offsets the benefit that is obtained through the steadily declining variance of inflation as can be seen by the top righthand graph in Figure 3.2. However, the variance of borrowing is also declining over the range of the reaction coefficient analysed. For reasonable parameterisations of the weight on aggregate borrowing in the loss function, the stronger the reaction of the policymaker the greater the gain in loss function under LATW for mandates one and two. In the case of mandate three, in which the regulator minimises a loss function constituted of output and financial stability, the increase in output stability more than offsets the gain from a reduction in the variability of borrowing volumes for parameterisations of $\beta < 1$.

The reduction in the variability of output in the case of CCR is due to the reduction in borrowing. In response to a technology shock, house prices rise pushing capital requirements higher and result in a lower level of borrowing, both for entrepreneur and impatient household. Tighter lending conditions result in fall in both the level of housing stock held by the entrepreneur and a

[11]These are given by the lefthand graphs in Figure 3.2

reduction in current investment expenditures that feeds through to the level of capital. After the initial period of growth, house prices begin to fall and lending conditions loosen causing an increase in investment thus generating the dynamics seen in the impulse response function of output in Figure **??** below. These dynamics are absent in in the case of LATW policy. When the technology shock hits the reduction in borrowing is marginal and the impact on investment relatively small. Most interesting is the noticeable difference in the variability of inflation given each type of policy. One possible explanation is that the contractionary response of the policy rate is damped in the case of LATW as the increase in house prices mitigates the reduction in policy rate resulting from the fall in inflation.

Figure 3.2: Policy mandates: varying ϕ^{ν} (Technology)



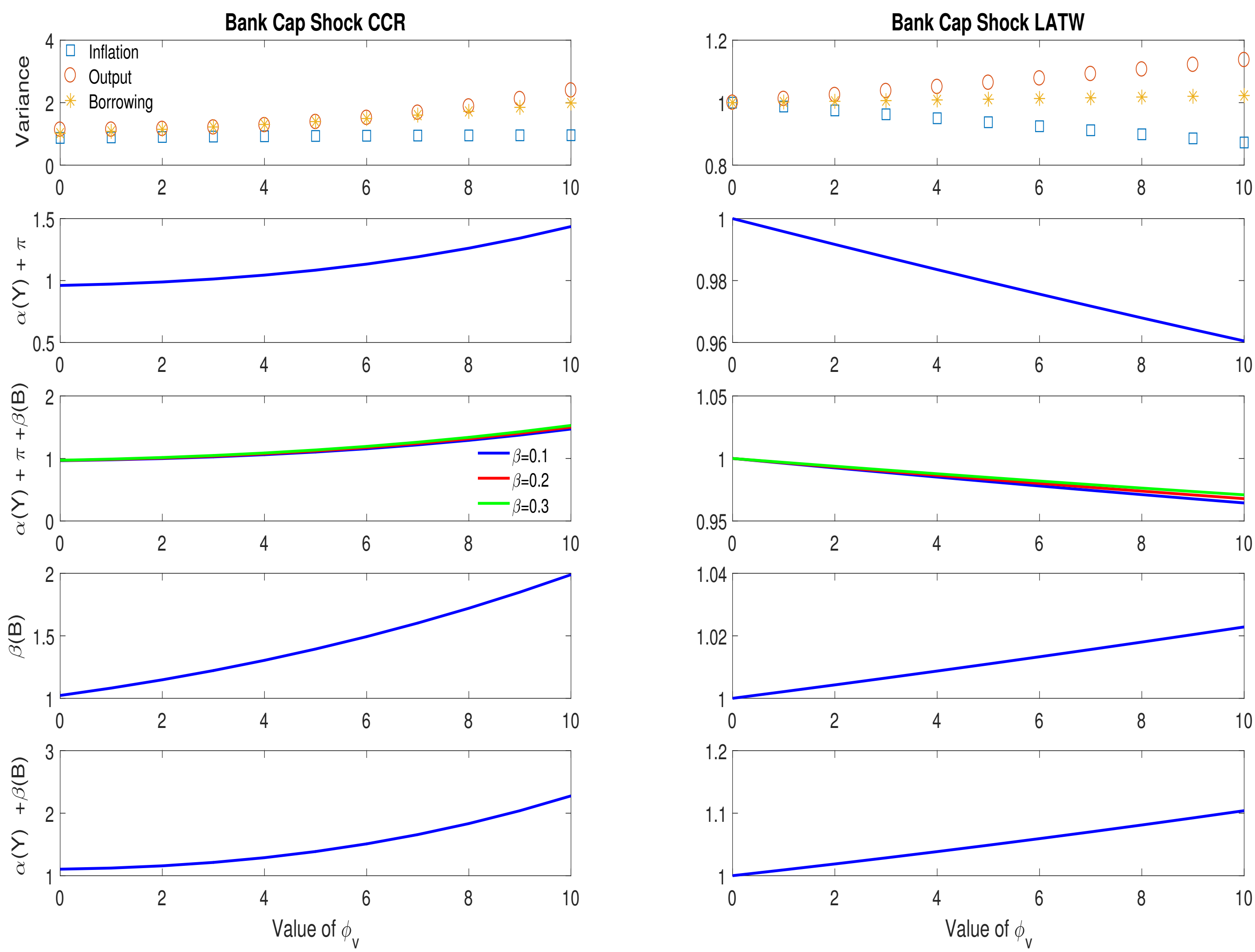
3.4.2 Bank Capital Shock

As in Ferreira and Nakane (2015), a bank capital shock is equivalent to an unexpected obsolescence of bank capital stock. When a bank capital shock occurs, this immediately impacts borrowing as the bank pays a cost for deviating from the capital requirements set by the policymaker. However, the reduction in borrowing puts downward pressure on house prices causing a loosening of capital requirements. As capital requirements loosen, current investment expenditures increase.

As can be seen from Figure 3.3, if capital requirement policy is active the variance of output, inflation and borrowing increase relative to the case of the benchmark model. In the case of output, as ϕ^{ν} increases the change in the variance rises at an increasing rate. This is perhaps generated through the response of investment. In the case of active CCR a fall in house prices loosens capital requirements. When this occurs, firm borrowing increases relative to the benchmark model pushing up investment expenditures. As house prices recover, capital requirements begin to tighten and banks fund the required increase in equity through higher interest rates on loans to households and entrepreneurs. This generates cyclical behaviour in borrowing which feeds through to a greater variance of investment and, by extension, output. The variance of inflation increases for low values of the reaction coefficient, reaching a peak when $\phi^{\nu} = \{7, 8\}$. Like output, the variance of borrowing increases over the range of ϕ^{ν} albeit linearly. Due to the variance of both output and borrowing, all mandates under CCR return a net loss for reasonable parameterisations of β.

In the case of LATW policy, the variance of inflation falls and variance of output increases relative to the benchmark model as ϕ^{ν} rises. This can be seen in the top righthand panel of 3.3. When a bank capital shock hits, the fall in house prices makes the reduction in the policy rate more pronounced. Although investment expenditures and entrepreneur borrowing falls, the fall in policy rate somewhat mitigates the decline in consumption relative to the benchmark where no macro-prudential policy is in place. In terms of alternate mandates, where the policymaker's loss function is constituted of an inflation component the loss functions return substantial improvements over the benchmark case. However, in the case of mandate two and three - i.e., where the financial regulator minimises a loss function constituted of output stability and/or borrowing stability - LATW returns losses as the variance of output and borrowing both increase relative to the benchmark model with no macro-prudential policy.

Figure 3.3: Policy mandates: varying ϕ^{ν} (Bank capital)



3.4.3 Monetary Policy Shock

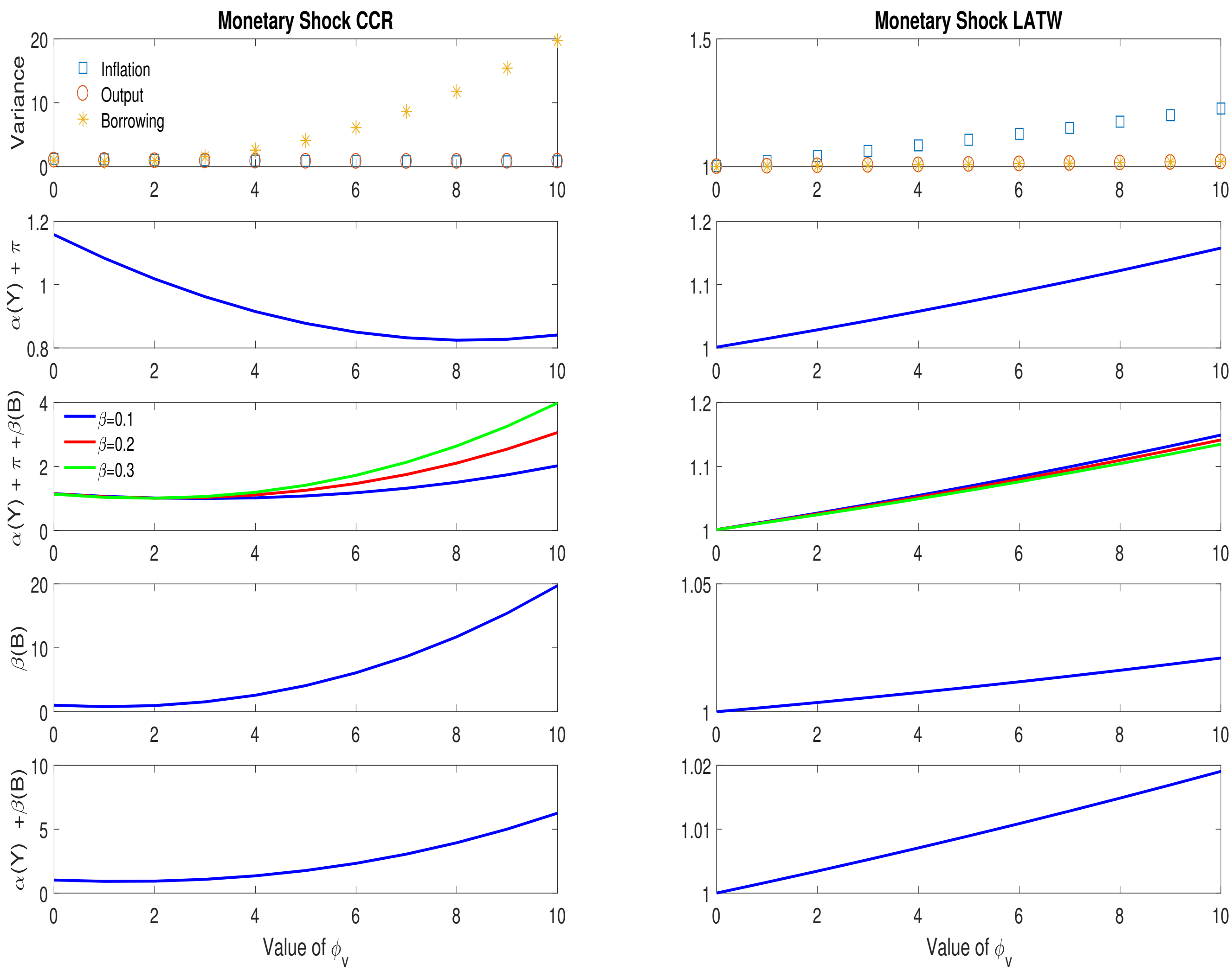
In the case of CCR, the variance of output is decreasing for all values of $\phi^{\nu} =< 8$; the variance of inflation is also decreasing for all values of $\phi^{\nu} < 9$; at these respective point the variances of both variables begin to increase as can be seen in Table 3.6. The variance of borrowing also decreases, but reaches a minimum when $\phi^{\nu} = 0$. This can be explained by the relative change in bank capital and aggregate borrowing. When a monetary shock hits, this feeds through the collateral channel reducing the net present value of said collateral by pulling up lending rates for both impatient households and entrepreneurs and puts downward pressure on house prices. The reduction in house prices reduces the capital requirement, countering the reduction in borrowing that would occur if CCR was not active. The overall impact is that the change in borrowing is less than the change in bank capital, effectively loosening the collateral constraint relative to the benchmark model. The fall in the variability of output is largely due to the reduction in the variability of investment, which is reduced by 23% relative to the benchmark model. In terms of alternate mandates, for values of reaction coefficient less than two each loss function indicates that macro-prudential policy improves the variance of each the variables over the benchmark model. However, for all values of $\phi^{\nu} > 2$, the variance of borrowing increases at an accelerating rate. Therefore, all mandates which include explicitly borrowing - i.e., mandates one for the central bank, and two and three for the financial regulator - return a loss over the benchmark case.

Figure 3.4 shows the increase in the variability of output, inflation and borrowing from a monetary policy shock when LATW is active relative to the benchmark case. In the benchmark model a monetary policy shock is partially offset by contemporaneous endogenous changes in output and inflation.[12] When LATW policy is active and anchored by house price growth, this further

[12]In the policy rule stated above, the policy rate responds immediately to output and inflation. Sensitivity analysis showed that re-specifying the policy rule so as to move at a one period lag of each does not significantly alter the results.

mitigates the direct impact of the shock. As explained above, when the policy rate increases this puts downward pressure on house prices. As output, inflation and house prices all decrease this endogenously reduces the policy rate. Due to the increase in the variance of each of the variables over the full range of ϕ^{ν} examined, all three mandates indicate that macro-prudential policy, either in the form of CCR or LATW, leads to substantial losses for both the central bank and the financial regulator

Figure 3.4: Policy mandates: varying ϕ^{ν} (Monetary)

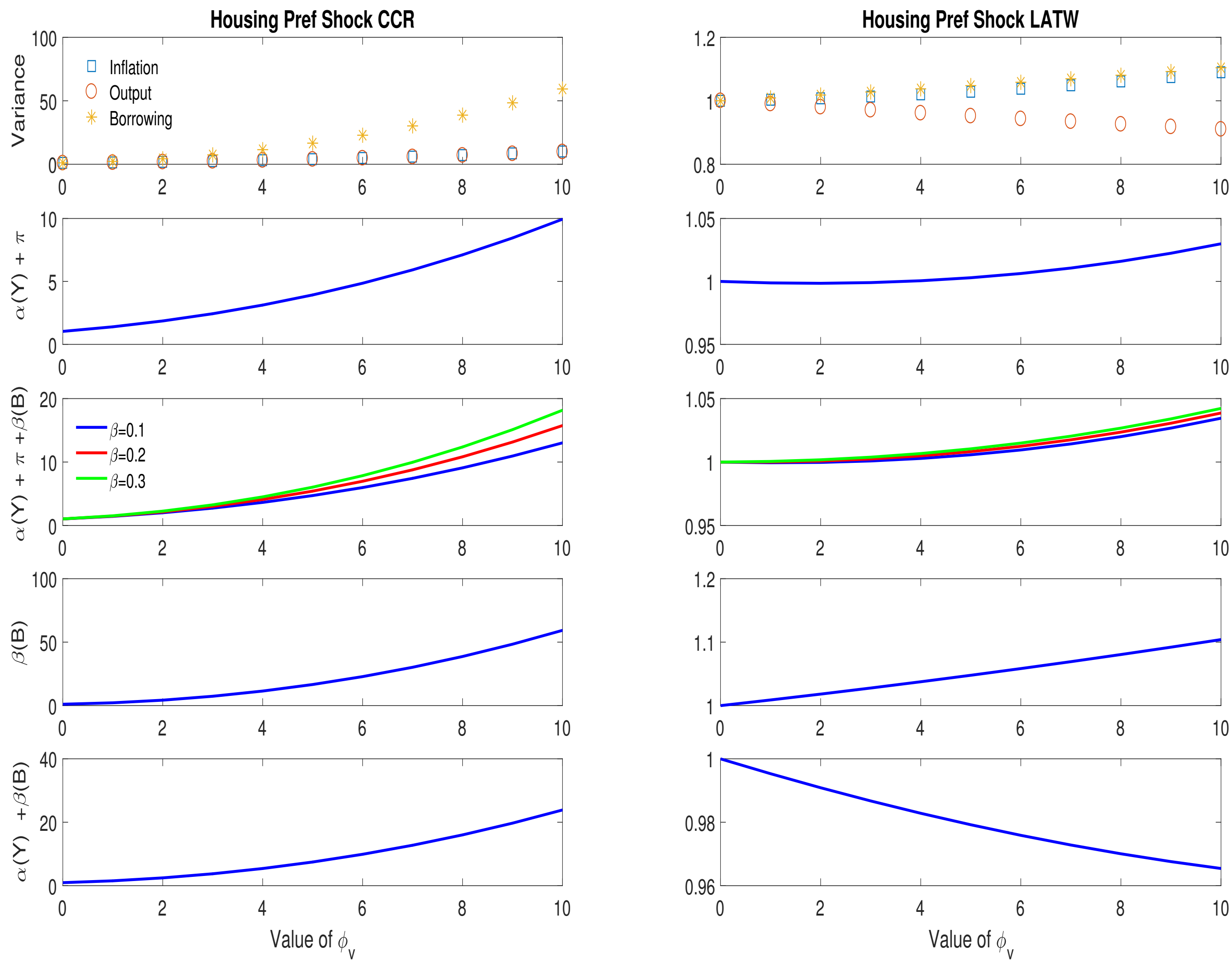


3.4.4 Housing Preference Shock

As is common elsewhere in the literature, a shock to the marginal rate of substitution between housing and consumption acts as a housing demand shock. This will impact patient and impatient households, putting upward pressure on the price of housing. As it is assumed entrepreneurs do not value housing services - their demand for the asset being derived from the value it provides by relaxing the borrowing constraint - the stock of housing held by the entrepreneur falls when the model is impacted by a housing preference shock, shifting the fixed stock of housing towards households. When CCR is active entrepreneur borrowing falls due to the reduction in their holdings of the housing asset. This if further compounded by a contemporaneous tightening of the capital requirement resulting from the rise in house price. Interestingly, the response of an increase in capital requirements causes investment to switch signs and decrease relative to benchmark. This contributes significantly to the increase in the volatility of output evidenced in Table 3.6. As the variance of output, inflation and borrowing is increasing over all values of ϕ^{ν} considered, CCR does not improve over the benchmark model where no macro-prudential policy is active for each of the three mandates considered.

In the case of LATW, the the variability of inflation and borrowing increase while that of output falls. As the weight placed on the variability of output is half that on inflation, the increase in the latter dominates the decrease in the former. Therefore, under mandate one the inclusion of LATW policies does not yield an improvement in the loss function. This holds true for mandate two also. However, in the case of mandate three, where the financial regulator minimises the variance of output and borrowing, higher values of ϕ^{ν}, over the range considered, do yield an improvement over the benchmark case when the weight on borrowing in the loss function is less than $\beta = 0.8$.

Figure 3.5: Policy mandates: varying ϕ^{ν} (Housing)

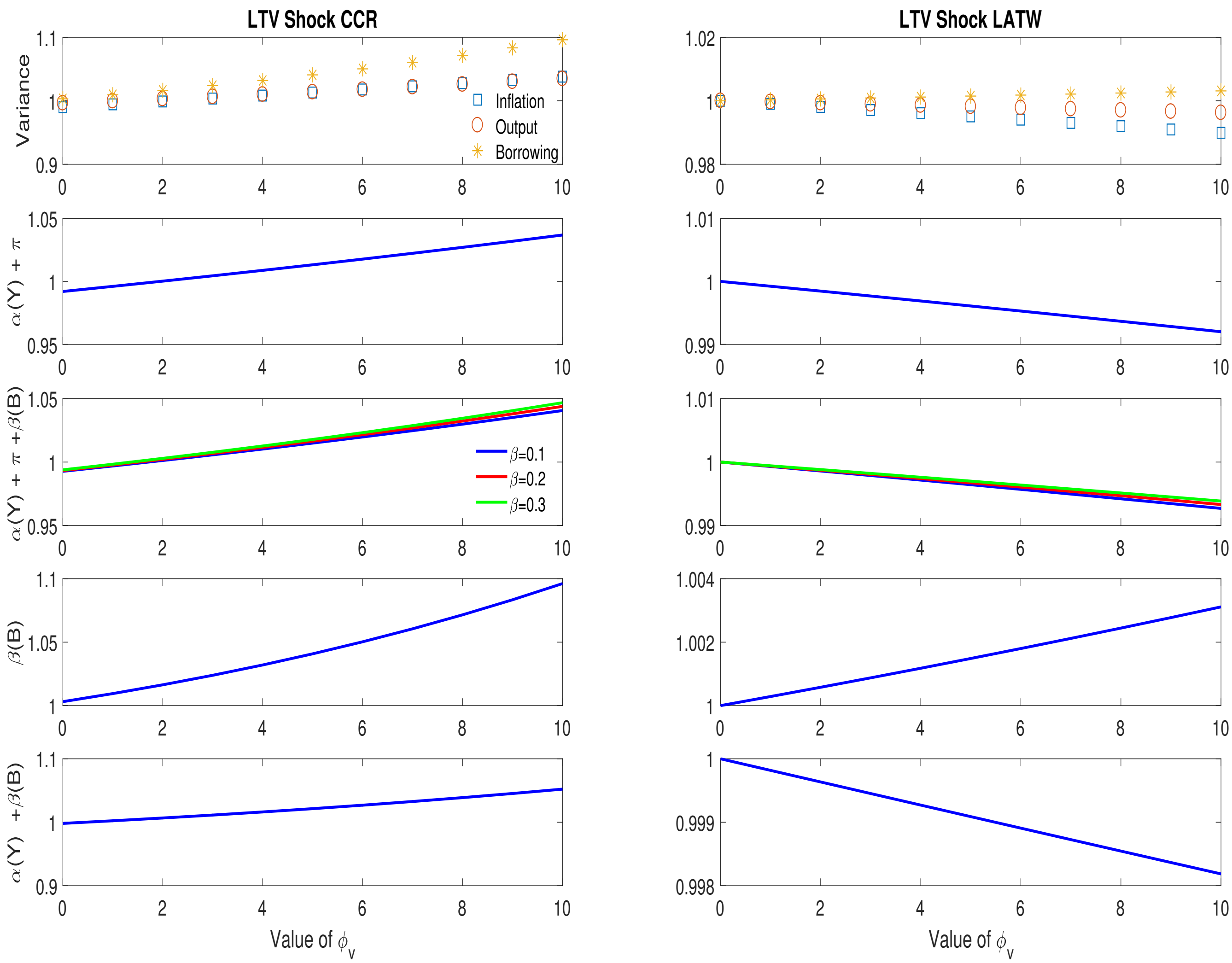


3.4.5 LTV Shock

An increase in the the LTV ratio expands the impatient households ability to raise funds against their stock of the housing asset, whilst also allowing the entrepreneur to utilise their stock of both the housing asset and capital to access borrowing. As the housing asset serves to increase the access to borrowing of both agents, an increase in the LTV ratio leads to competition between credit constrained borrowers for the fixed supply of the housing asset, shifting the holding of the asset away from patient households whilst also putting upward pressure on the price. As the shock also enhances the ability of entrepreneurs to borrow against current capital, entrepreneur borrowing increases allowing for a higher level of investment expenditure. When macro-prudential policy is in the form of CCR, the variance of inflation, output and borrowing each increase over the full range of ϕ^{ν} relative to the benchmark case. Therefore, under each of the three mandates considered, macro-prudential policy policy does not yield an improvement over simulations of the model when said policy is inactive.

In terms of macro-prudential policy in the form of LATW, the variance of output and inflation fall unambiguously over the range of ϕ^{ν} examined; however, the variance of borrowing increases linearly over said range. When LATW policy is assessed in terms of the mandates specified above, only in the case of mandate two, where the financial regulator minimises a loss function in terms of financial-stability only, does LATW not yield an improvement over the benchmark model. Where a financial stability measure is included in the standard loss functions, the loss function returns a gain until the weight on financial stability is a multiple of 4 that on output stability.

Figure 3.6: Policy mandates: varying ϕ^{ν} (LTV)



3.5 Optimal ϕ^{ν} and Model Responses

The optimal policy response of both the central bank and, where applicable by mandate, the financial regulator are indicated in tables 3.3 and 3.4 below. These were calculated by simulating the model over the range $\phi^{\nu} = \{0 : 10\}$ in discrete jumps of 0.1. For each simulation the mandates were calculated and the optimal value of ϕ^{ν} was drawn from the minimum of each mandate.

Table 3.3: Optimal policy under CCR

		Mandate One		Mandate Two		Mandate Three	
	β	L_{CB}	-	L_{CB}	L_{reg}	L_{CB}	L_{reg}
Monetary	$\beta = 0.1$	2.9	-	7.2	1.2	7.2	1.8
	$\beta = 0.2$	2.2	-	7.2	1.2	7.2	1.5
	$\beta = 0.3$	1.9	-	7.2	1.2	7.2	1.5

Figures are relative to benchmark model where macroprudential policy is not active.

Given the range of policy mandates specified above, under some shocks the optimal value of the policy response was found to be either zero or unbounded. This was more prevalent in the case of CCR where only in receipt of a monetary policy shock does the macro-prudential policy offer a gain over the benchmark model response. As the table above shows, there is a notable conflict between the central bank and financial regulator when the latter minimises ϕ^{ν} for a loss function which includes a measure of financial stability, here aggregate borrowing. Specifically, the central bank,would opt for a stronger macro-prudential response than the financial regulator. In the case of mandate one, the larger the weight attached to stabilising the financial stability measure, the weaker the response of macro-prudential policy due to the significant increase in borrowing caused by higher values of ϕ^{ν}.

Table 3.4: Optimal policy under LATW

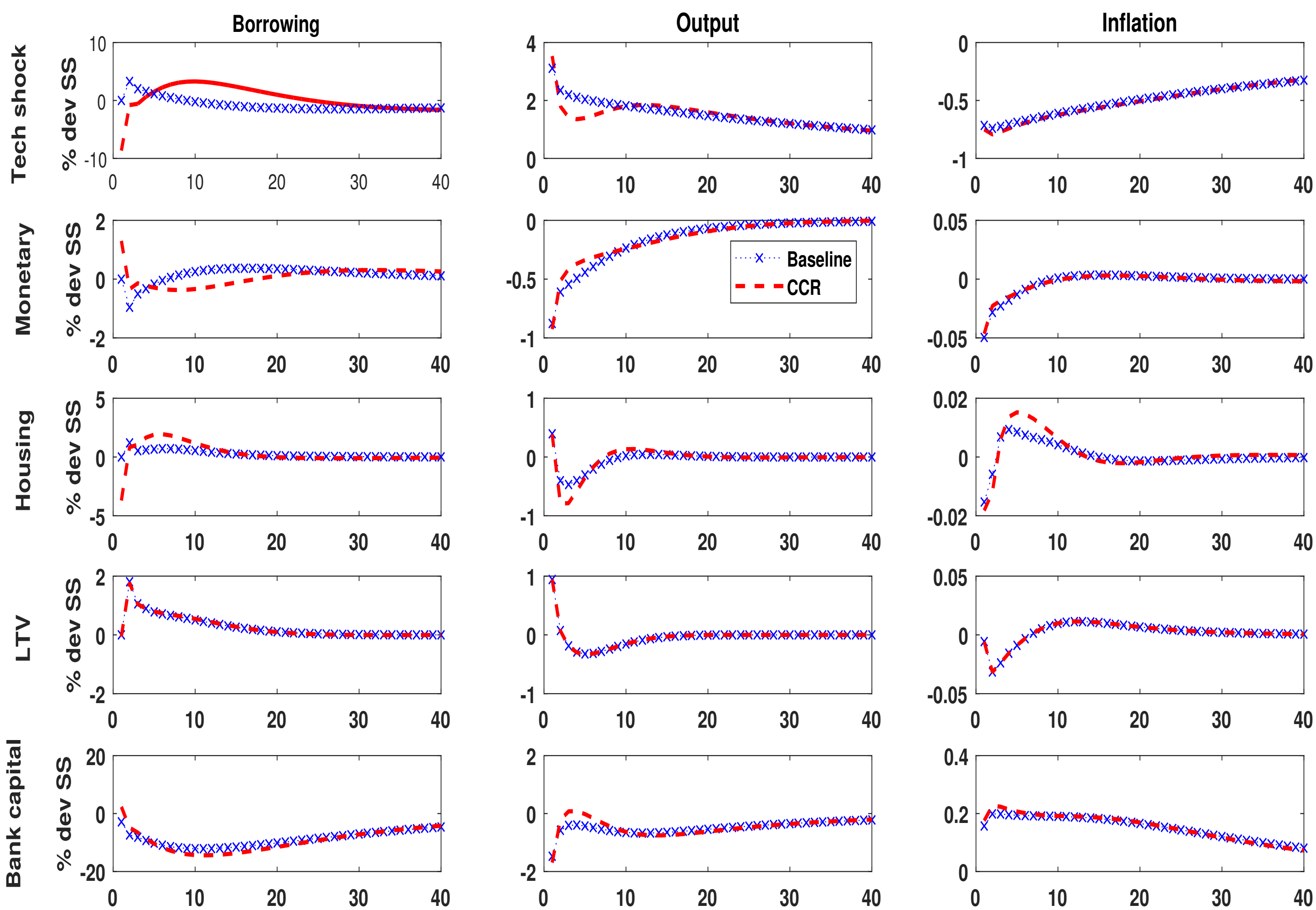
		Mandate One		Mandate Two		Mandate Three	
	β	L_{CB}	-	L_{CB}	L_{reg}	L_{CB}	L_{reg}
Technology	$\beta = 0.1$	∞	-	∞	∞	∞	0
	$\beta = 0.2$	∞	-	∞	∞	∞	0
	$\beta = 0.3$	∞	-	∞	∞	∞	0
		Mandate One		Mandate Two		Mandate Three	
	β	L_{CB}	-	L_{CB}	L_{reg}	L_{CB}	L_{reg}
Bank Cap	$\beta = 0.1$	∞	-	∞	0	∞	0
	$\beta = 0.2$	∞	-	∞	0	∞	0
	$\beta = 0.3$	∞	-	∞	0	∞	0
		Mandate One		Mandate Two		Mandate Three	
	β	L_{CB}	-	L_{CB}	L_{reg}	L_{CB}	L_{reg}
Housing	$\beta = 0.1$	0.8	-	0	0	0	∞
	$\beta = 0.2$	0.6	-	0	0	0	∞
	$\beta = 0.3$	0	-	0	0	0	∞
		Mandate One		Mandate Two		Mandate Three	
	β	L_{CB}	-	L_{CB}	L_{reg}	L_{CB}	L_{reg}
LTV	$\beta = 0.1$	∞	-	∞	0	∞	∞
	$\beta = 0.2$	∞	-	∞	0	∞	∞
	$\beta = 0.3$	∞	-	∞	0	∞	∞

Figures are relative to benchmark model where macroprudential policy is not active.

Table 3.4 shows the optimal response of macro-prudential policy. Surprisingly, the optimal policy response in all cases bar two is either 0 or ∞. However, as can be seen in figures 3.2, 3.3, 3.5, 3.6 above, under LATW policy the variances of output, inflation and borrowing do not, in any of the four shock scenarios, increase(decrease) jointly. Therefore, the resultant optimal policy parameters are not invariant to weights attached to output, inflation and borrowing.

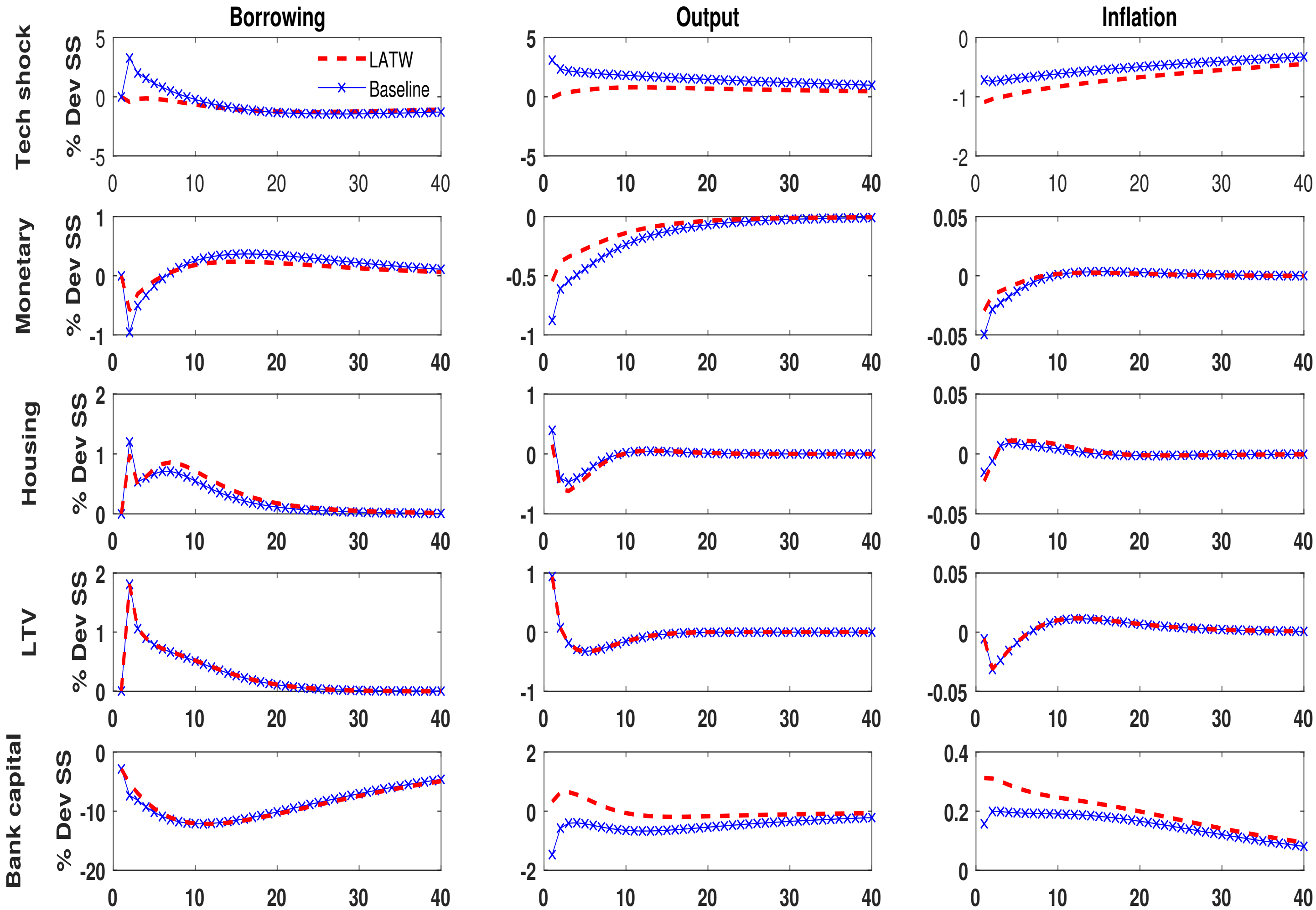
Figures 3.7 and 3.8 below provide the responses of output, inflation and borrowing for each type of macro-prudential policy.[13]

Figure 3.7: Impulse Responses: Baseline v CCR



[13]As is clear from tables 3.3 and 3.4, it is not possible, other than in the case of a technology shock under CCR, to simulate the model given over the various optimal policy parameters as would be expected in order to graphically display the resultant impulse responses relative to baseline. Ideally, the optimal policy parameter would be bounded for each shock and each type of macro-prudential policy. Therefore, the simulation which generated the impulses used $\phi^{\nu} = 5$ as a mid-point for LATW, and took the optimal parameter $\phi^{\nu} = 2.9$ for CCR as per table 3.3.

Figure 3.8: Impulse Responses: Baseline v LATW



3.6 Conclusion

This paper has examined two types of macro-prudential policy in an estimated DSGE model with a banking sector. Both in the case of capital requirements and a lean-against-the-wind type Taylor Rule, policy was anchored to house price growth. The paper extends the analysis along the lines of Gambacorta and Signoretti (2014) through allowing housing to be posted as collateral, anchoring policy to a widely accepted metric in the form of house prices, and considers a wider variety of shocks.

Using a range of alternate specifications of central bank loss functions as metrics to gauge the efficacy of macro-prudential policy, the results highlight the tendency for policy to both exacerbate and/or dampen the volatility of output, inflation and aggregate borrowing dependent on the source of the shock. In the case of both a technology and monetary policy shock macro-prudential in the form of capital requirements offers improvements in the variation of output of up to 7.38% and 22.14%, respectively. However, CCR exacerbates fluctuations in inflation in the case of technology shock in the region of 4.99%. If the source of the shock is through housing preference, LTV or bank capital, policy in this form unambiguously increases the variance of output, inflation and borrowing. If policy takes the form of LATW, the output-inflation trade-off is more pronounced in the case of a technology shock. The improvements in reducing the variance of output and inflation are lessened when LATW is active rather than CCR over the range considered for a monetary policy shock, albeit qualitatively similar. Interestingly, in the case of a bank capital shock LATW reduces the variance of output.

The analysis is extended to examine the spillover effects on house prices and broad credit volumes of macro-prudential policy. LATW reduces the variance of house prices for all shocks considered with gains reaching 11.32% in the case of a housing preference shock. However, when policy is in the form of CCR this increases the variance of house prices both when housing preference or LTV shock hits. Importantly, CCR generate substantial fluctuations in broad credit volumes. An interesting extension would be to include borrowing inertia. Estimates of the inertia of borrowing are in the region of 0.65-0.7 (Iacoviello, 2015) for both impatient households and entrepreneurs. If borrowing volumes exhibited the degree of persistence observed in the data, this could lead to a reassessment of the efficacy of capital requirements as a tool that reduces the loss function.

3.A Appendix A - Relative variances

Table 3.5: LATW Macro-prudential policy anchored by house price growth (Standard Deviations)

	Technology			Monetary Policy			Housing Preference			LTV			Bank Capital		
ϕ^{ν}	π_t	Y_t	B_t	π_t	Y_t	B_t	π_t	Y_t	B_t	π_t	Y_t	B_t	π_t	Y_t	B_t
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	-0.72%	0.27%	-0.24%	1.93%	0.17%	0.18%	0.33%	-1.01%	0.89%	-0.10%	-0.04%	0.03%	-1.23%	1.21%	0.21%
2	-1.42%	0.55%	-0.47%	3.93%	0.34%	0.36%	0.78%	-2.00%	1.82%	-0.19%	-0.07%	0.06%	-2.45%	2.45%	0.43%
3	-2.14%	0.83%	-0.68%	5.99%	0.51%	0.55%	1.34%	-2.96%	2.77%	-0.29%	-0.11%	0.09%	-3.73%	3.73%	0.65%
4	-2.86%	1.11%	-0.87%	8.12%	0.69%	0.75%	2.03%	-3.90%	3.76%	-0.39%	-0.15%	0.12%	-4.99%	5.04%	0.87%
5	-3.58%	1.40%	-1.04%	10.33%	0.87%	0.96%	2.85%	-4.82%	4.78%	-0.49%	-0.19%	0.15%	-6.26%	6.39%	1.10%
6	-4.31%	1.69%	-1.20%	12.61%	1.05%	1.17%	3.80%	-5.71%	5.84%	-0.59%	-0.22%	0.18%	-7.54%	7.77%	1.33%
7	-5.03%	1.99%	-1.34%	14.97%	1.24%	1.39%	4.88%	-6.57%	6.93%	-0.70%	-0.26%	0.21%	-8.83%	9.18%	1.56%
8	-5.76%	2.29%	-1.47%	17.41%	1.43%	1.62%	6.10%	-7.41%	8.05%	-0.80%	-0.30%	0.24%	-10.13%	10.63%	1.80%
9	-6.50%	2.59%	-1.58%	19.93%	1.63%	1.86%	7.47%	-8.22%	9.21%	-0.90%	-0.34%	0.28%	-11.43%	12.12%	2.04%
10	-7.23%	2.90%	-1.67%	22.54%	1.83%	2.10%	8.99%	-9.00%	10.41%	-1.01%	-0.38%	0.31%	-12.75%	13.64%	2.28%

Figures are relative to benchmark model where macroprudential policy is not active.

Table 3.6: CCR Macroprudential policy anchored by house price growth (Standard Deviations)

	Technology			Monetary Policy			Housing Preference			LTV			Bank Capital		
ϕ^ν	π_t	Y_t	B_t	π_t	Y_t	B_t	π_t	Y_t	B_t	π_t	Y_t	B_t	π_t	Y_t	B_t
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	1.19%	-2.53%	1.96%	-7.29%	-5.33%	-26.11%	35.87%	34.39%	106.11%	0.41%	0.30%	0.64%	1.15%	-0.77%	5.70%
2	2.28%	-4.60%	61.92%	-13.66%	-10.03%	-14.15%	81.95%	79.20%	308.17%	0.83%	0.61%	1.32%	2.12%	0.76%	12.09%
3	3.28%	-6.15%	183.77%	-19.10%	-14.03%	37.95%	138.78%	134.78%	608.62%	1.25%	0.93%	2.07%	2.92%	4.77%	19.20%
4	4.18%	-7.10%	373.17%	-23.61%	-17.30%	132.33%	206.96%	201.47%	1009.98%	1.68%	1.26%	2.87%	3.56%	11.45%	27.08%
5	4.99%	-7.38%	634.58%	-27.21%	-19.77%	271.20%	287.07%	279.64%	1514.97%	2.12%	1.60%	3.73%	4.05%	20.99%	35.76%
6	5.71%	-6.93%	972.81%	-29.88%	-21.40%	456.85%	379.75%	369.68%	2126.44%	2.56%	1.96%	4.65%	4.40%	33.57%	45.27%
7	6.34%	-5.67%	1392.70%	-31.62%	-22.14%	691.67%	485.67%	471.99%	2847.40%	3.01%	2.33%	5.65%	4.62%	49.39%	55.66%
8	6.90%	-3.54%	1899.22%	-32.42%	-21.92%	978.20%	605.53%	587.00%	3681.08%	3.46%	2.72%	6.71%	4.72%	68.66%	66.97%
9	7.38%	-0.46%	2497.46%	-32.27%	-20.69%	1319.09%	740.08%	715.16%	4630.90%	3.92%	3.12%	7.86%	4.72%	91.57%	79.23%
10	7.79%	3.65%	3192.69%	-31.16%	-18.38%	1717.18%	890.09%	856.96%	5700.51%	4.40%	3.53%	9.08%	4.63%	118.34%	92.50%

Figures are relative to benchmark model where macroprudential policy is not active.

3.B Appendix B - Model Equations and Model Fit

3.B.1 Steady State Model Block

Patient Household

$$\lambda_1 = \frac{1}{C_1} \tag{3.27}$$

$$\frac{1}{C_1} = \frac{L_l^{\phi}}{w_1} \tag{3.28}$$

$$\frac{1}{C_1} = \frac{\beta_1(1+r^d)}{C_1} \Longrightarrow r^d = \frac{1-\beta_1}{\beta_1} \tag{3.29}$$

$$q^h = \frac{\Omega C_1}{(1-\beta_1)h_1} \tag{3.30}$$

Impatient Household

$$\lambda_2 = \frac{1}{C_2} \tag{3.31}$$

$$\frac{1}{C_2} = \frac{L_l^{\phi}}{w_2} \tag{3.32}$$

$$\frac{1}{C_2} = \frac{\beta_2(1+r^{bh})}{C_2} + (1+r_t^{bh})\lambda_3 \Longrightarrow \lambda_3 = \frac{1-\beta_2(1+r^{bh})}{C_2(1+r_t^{bh})} \tag{3.33}$$

$$q^h = \frac{\Omega C_2}{h_{2,t}} + \beta_2 q_h + \lambda_3 m^h q^h C_2 \Longrightarrow q^h \left(1 - \beta_2 - \frac{(1-\beta_2(1+r^{bh}))m^h}{(1+r^{bh})}\right) = \frac{\Omega C_2}{h_2} \tag{3.34}$$

Entrepreneur

$$\lambda_4 = \frac{1}{C_3} \tag{3.35}$$

$$w_1 = \alpha(1-\mu-\eta)\frac{Y}{L_1 X} \tag{3.36}$$

$$\frac{1}{C_3} = \frac{\beta_3(1+r^{be})}{C_3} + (1+r_t^{be})\lambda_5 \Longrightarrow \lambda_5 = \frac{1-\beta_3(1+r^{be})}{(1+r_t^{be})C_3} \tag{3.37}$$

$$q^k = \beta_3 q^k + \lambda_5 m^k q^k (1-\delta^k) C_3 + \mu\frac{Y}{XK} \Longrightarrow q^k\left(1-\beta_3(1-\delta^k) - \frac{(1-\beta_3(1+r^{be}))m^k(1-\delta^k)}{(1+r^{be})}\right) = \mu\frac{Y}{XK} \tag{3.38}$$

$$q^k = 1 \tag{3.39}$$

$$q^h = \beta_3 q^h + \lambda_5 m^h q^h C_3 + \eta\frac{Y_t}{h_3 X} \Longrightarrow q^h\left(1-\beta_3 - \frac{(1-\beta_3(1+r^{be}))m^h}{(1+r^{be})}\right) = \eta\frac{Y_t}{h_3 X} \tag{3.40}$$

Banking Sector

$$R^b = r \tag{3.41}$$

$$S^w = R^b - r^d \tag{3.42}$$

$$r^{b\{e,h\}} = \left(\frac{\epsilon^{b\{e,h\}}}{\epsilon^{b\{e,h\}}-1}\right)R^b \tag{3.43}$$

$$r^d = \left(\frac{\epsilon^d}{\epsilon^d-1}\right)r \tag{3.44}$$

$$S^b = r^b - r = \left(\frac{1}{\epsilon^{b\{e,h\}}-1}\right)r + \left(\frac{\epsilon^{b\{e,h\}}}{\epsilon^{b\{e,h\}}-1}\right)S^w \tag{3.45}$$

$$J^b = \delta^b K^b \tag{3.46}$$

3.B.2 Linearised Model Block

Patient Household

$$\tilde{\lambda}_{1,t} = \phi \tilde{L}_{1,t} - \tilde{w}_{1,t} \tag{3.47}$$

$$\tilde{\lambda}_{1,t} = -(1/(1-\gamma))\tilde{C}_{1,t} + (\gamma/(1-\gamma))\tilde{C}_{1,t-1} \tag{3.48}$$

$$\tilde{\lambda}_{1,t} = \tilde{\lambda}_{1,t+1} + (1-\beta_1)\,\tilde{r}^d_t \tag{3.49}$$

$$\tilde{q}^h_t = \beta_1(\tilde{\lambda}_{1,t+1} + \tilde{q}^h_{t+1} - \tilde{\lambda}_{1,t}) + (1-\beta_1)(\tilde{\Omega}_t - \tilde{\lambda}_{1,t} - \tilde{h}_{1,t}) \tag{3.50}$$

Impatient Household

$$\tilde{\lambda}_{2,t} = \phi \tilde{L}_{2,t} - \tilde{w}_{2,t} \tag{3.51}$$

$$\tilde{\lambda}_{2,t} = -(1/(1-\gamma))\tilde{C}_{2,t} + (\gamma/(1-\gamma))\tilde{C}_{2,t-1} \tag{3.52}$$

$$\tilde{\lambda}_{2,t} = [\beta_2(1+r^{bh})]\tilde{\lambda}_{2,t+1} + \left(\beta_2 r^{bh} + \left(\frac{(1-\beta_2(1+r^{bh}))}{(1+r^{bh})}\right) r^{bh}\right)\tilde{r}^{bh}_t + [1-\beta_2(1+r^{bh})]\tilde{\lambda}_{3,t} \tag{3.53}$$

$$\begin{aligned}\tilde{q}^h_t &= \beta_2(\tilde{\lambda}_{2,t+1} + \tilde{q}^h_{t+1} - \tilde{\lambda}_{2,t}) + \left(1 - \beta_2 - \frac{(1-\beta_2(1+r^{bh}))m^h}{(1+r^{bh})}\right)(\tilde{\Omega}_t - \tilde{\lambda}_{2,t} - \tilde{h}_{2,t}) \\ &\quad + \left(\frac{(1-\beta_2(1+r^{bh}))m^h}{(1+r^{bh})}\right)\left(\tilde{m}^h_t + \tilde{q}^h_{t+1} + \tilde{\lambda}_{3,t} - \tilde{\lambda}_{2,t}\right)\end{aligned} \tag{3.54}$$

Entrepreneur

$$\tilde{\lambda}_{4,t} = -(1/(1-\gamma))\tilde{C}_{3,t} + (\gamma/(1-\gamma))\tilde{C}_{3,t-1} \tag{3.55}$$

$$\tilde{\lambda}_{4,t} = [\beta_3(1+r^{be})]\tilde{\lambda}_{4,t+1} + \left(\beta_3 r^{be} + \left(\frac{(1-\beta_3(1+r^{be}))}{(1+r^{be})}\right) r^{be}\right)\tilde{r}^{be}_t + [1-\beta_3(1+r^{be})]\tilde{\lambda}_{5,t} \tag{3.56}$$

$$\tilde{w}_{1,t} = \tilde{Y}_t - \tilde{L}_{1,t} - \tilde{X}_t \tag{3.57}$$

$$\tilde{w}_{2,t} = \tilde{Y}_t - \tilde{L}_{2,t} - \tilde{X}_t \tag{3.58}$$

$$\begin{aligned}\tilde{q}^k_t &= [\beta_3(1-\delta^k)](\tilde{\lambda}_{4,t+1} - \tilde{\lambda}_{4,t} + \tilde{q}^k_{t+1}) + \left(\frac{(1-\beta_3(1+r^{be}))m^k(1-\delta^k)}{(1+r^{be})}\right)(\tilde{q}^k_{t+1} - \tilde{\lambda}_{4,t} + \tilde{\lambda}_{5,t} + \tilde{m}^k_t)\\ &+ \left[1-\beta_3(1-\delta^k) - \left(\frac{(1-\beta_3(1+r^{be}))m^k(1-\delta^k)}{(1+r^{be})}\right)\right](\tilde{\lambda}_{4,t+1} - \tilde{\lambda}_{4,t} + \tilde{Y}_{t+1} - \tilde{X}_{t+1} - \tilde{K}_t)\end{aligned} \tag{3.59}$$

$$\tilde{q}^k_t = \kappa[(\tilde{I}_t - \tilde{I}_{t-1})] - \beta_3[(\tilde{I}_{t+1} - \tilde{I}_t)] \tag{3.60}$$

$$\begin{aligned}\tilde{q}^h_t &= \beta_3(\tilde{\lambda}_{4,t+1} - \tilde{\lambda}_{4,t} + \tilde{q}^h_{t+1}) + \left(\frac{(1-\beta_3(1+r^{be}))m^h}{(1+r^{be})}\right)\left(\tilde{q}^h_{t+1} - \tilde{\lambda}_{4,t} + \tilde{\lambda}_{5,t} + \tilde{m}^h_t\right)\\ &+ \left(1-\beta_3 - \left(\frac{(1-\beta_3(1+r^{be}))m^h}{(1+r^{be})}\right)\right)\left(\tilde{\lambda}_{4,t+1} - \tilde{\lambda}_{4,t} + \tilde{Y}_{t+1} - \tilde{h}_{3,t} - \tilde{X}_{t+1}\right)\end{aligned} \tag{3.61}$$

Banking Sector

$$\tilde{r}_t^{bh} = \tilde{r}_t^{be} \tag{3.62}$$

$$\tilde{r}_t^{b} = \tilde{R}_t^{b} \tag{3.63}$$

$$\tilde{r}_t^{d} = \tilde{r}_t \tag{3.64}$$

$$\tilde{B}_t = \nu \tilde{K}_t^b + (1-\nu)\tilde{D}_t \tag{3.65}$$

$$\tilde{R}_t^b = \tilde{r}_t^d + \left[\frac{\beta_1 \theta \nu^3}{1-\beta_1}\right](\tilde{B}_t - \tilde{K}_t^b + \tilde{\nu}_t) \tag{3.66}$$

$$\tilde{S}_t^b = \left[\frac{1}{1-\beta_1+\epsilon^{b\{e,h\}}\beta_1}\right]\Big((1-\beta_1)\tilde{r}_t + \epsilon^{b\{e,h\}}\beta_1 \tilde{S}_t^w\Big) \tag{3.67}$$

$$\frac{J^b}{B}\tilde{J}_t^b = \left[r^{bh}\frac{Y}{B}\frac{b^h}{Y}\right](\tilde{r}_t^b + \tilde{b}_t^h) + \left[r^{bh}\frac{b^e}{Y}\frac{Y}{B}\right](\tilde{r}_t^b + \tilde{b}_t^e) - \left(\frac{1-\beta_1}{\beta_1}\right)(\tilde{B}_t - \nu\tilde{K}_t^b) + \frac{\theta}{2}\nu^3\tilde{\nu}_t \tag{3.68}$$

$$\tilde{K}_t^b = (1-\delta^b)(\tilde{K}_{t-1}^b - \epsilon_t^k) + \delta^b \tilde{J}_t^b \tag{3.69}$$

Remaining Equations

$$\tilde{Y}_t = \tilde{A}_t + \mu\tilde{K}_{t-1} + \eta\tilde{h}_{3,t-1} + \alpha(1-\mu-\eta)\tilde{L}_{1,t} + (1-\alpha)(1-\mu-\eta)\tilde{L}_{2,t} \tag{3.70}$$

$$\tilde{K}_t = (1-\delta^k)\tilde{K}_{t-1} + \frac{I}{K}\tilde{I}_t \tag{3.71}$$

$$\tilde{Y}_t = \frac{C_1}{Y}\tilde{C}_{1,t} + \frac{C_2}{Y}\tilde{C}_{2,t} + \frac{C_3}{Y}\tilde{C}_{3,t} + \frac{K}{Y}\left(\tilde{K}_t - (1-\delta^k)\tilde{K}_{t-1} + \delta^k\tilde{q}_t^k\right) + \delta^b\frac{K^b}{Y}\tilde{K}_{t-1}^b \tag{3.72}$$

$$\tilde{r}_t = (1-r_r)((1+r_\pi)\tilde{\pi}_t - r_x\tilde{X}) + r_r\tilde{r}_{t-1} + \epsilon_{r,t} \tag{3.73}$$

$$\tilde{\pi}_t = \beta_1\tilde{\pi}_{t+1} + \left(\frac{\epsilon^y}{\kappa_p(\epsilon^y-1)X}\right)\tilde{X}_t + \tilde{\epsilon}_t^y \tag{3.74}$$

$$\begin{aligned}\frac{b^e}{Y}\tilde{b^e}_t = {} & \frac{C_3}{Y}\tilde{C}_{3,t} + \left(\frac{b^e}{Y}\right)\tilde{b}_{t-1}^e + \left(r^{be}\frac{b^e}{Y}\right)(\tilde{r}_{t-1}^{be} + \tilde{b}_{t-1}^e) + \left(\frac{K}{Y}\right)(\tilde{q}_t^k + \tilde{K}_t) - \left((1-\delta^k)\frac{K}{Y}\right)(\tilde{q}_t^k + \tilde{K}_{t-1}) \\ & + \frac{q^h h_3}{Y}(\tilde{h}_{3,t} - \tilde{h}_{3,t-1}) - \left(\frac{\mu+\eta}{X}\right)(\tilde{Y}_t - \tilde{X}_t)\end{aligned} \tag{3.75}$$

$$\frac{b^h}{Y}\tilde{b}_t^h = \frac{C_2}{Y}\tilde{C}_{2,t} + \left(r^{bh}\frac{b^h}{Y}\right)(\tilde{r}_{t-1}^{bh} + \tilde{b}_{t-1}^h) + \left(\frac{b^h}{Y}\right)\tilde{b}_{t-1}^h + \left(\frac{q^h h_2}{Y}\right)(\tilde{h}_{2,t} - \tilde{h}_{2,t-1}) - \left(\frac{(1-\alpha)(1-\mu-\nu)}{x}\right)(\tilde{Y}_t - \tilde{X}_t) \tag{3.76}$$

$$\tilde{b}_t^e = \left[\frac{m^h}{(1+r^{be})}\frac{q^h h_3}{Y}\frac{Y}{b_e}\right]\left(\tilde{q}_t^h + \tilde{h}_{3,t} + \tilde{m}_t^h\right) + \left[1 - \frac{m^h}{(1+r^{be})}\frac{q^h h_3}{Y}\frac{Y}{b_e}\right]\left(\tilde{q}_t^k + \tilde{K}_t + \tilde{m}_t^k\right) - \left(\frac{r^{be}}{1+r^{be}}\right)\tilde{r}_t^{be} \tag{3.77}$$

$$\tilde{b}_t^h = \tilde{m}_t^h + \tilde{q}_t^h + \tilde{h}_{2,t} - \left(\frac{r^{bh}}{1+r^{bh}}\right)\tilde{r}_t^{bh} \tag{3.78}$$

$$-\tilde{h}_{1,t} = \frac{h_2}{h_1}\tilde{h}_{2,t} + \frac{h_3}{h_1}\tilde{h}_{3,t} \tag{3.79}$$

$$\tilde{B}_t = \left(\frac{b_e}{b_e - b_h}\right)\tilde{b}_t^e + \left(\frac{b_h}{b_e - b_h}\right)\tilde{b}_t^h \tag{3.80}$$

Table 3.7: Full Model Steady State Values v Data

Parameter	Description	Model SS	Data
c/y	Ratio of consumption to GDP	0.81	0.68
i/y	Ratio of investment to GDP	0.21	0.17
k/y	Ratio of capital stock to GDP	4.28	3.19
b/y	Ratio fo loans to GDP	3.39	1.49
bh/y	Ratio of household loans to GDP	1.48	0.84
be/y	Ratio of business loans to GDP	1.91	0.66

Table 3.8: Model Performance: Standard Deviations and Cross Correlations

Variable	*SD%*	**Benchmark Model**								
	σ_y/σ_x	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)
Output	1	0.87	0.89	0.91	0.94	1	0.94	0.91	0.89	0.87
Consumption	1.28	0.92	0.93	0.94	0.95	0.99	0.95	0.94	0.93	0.92
Investment	1.55	0.18	0.22	0.27	0.34	0.72	0.34	0.27	0.22	0.18
House Prices	2.11	0.89	0.91	0.93	0.94	0.97	0.94	0.93	0.91	0.89
		Data								
	σ_y/σ_x	x(-4)	x(-3)	x(-2)	x(-1)	x	x(+1)	x(+2)	x(+3)	x(+4)
Output	1	0.31	0.50	0.70	0.88	1	0.88	0.70	0.50	0.31
Consumption	0.81	0.31	0.51	0.69	0.84	0.91	0.86	0.74	0.57	0.40
Investment	5.75	0.41	0.55	0.71	0.85	0.93	0.83	0.63	0.39	0.17
House Price	3.65	0.45	0.54	0.63	0.66	0.65	0.56	0.44	0.34	0.30

All variables have been deflated using the implicit price deflator (IPD), logged and first differenced. Standard deviations have been normalised for GDP.

3.C Appendix B - Estimation Details

3.C.1 Data

Data used in estimating the model covers the period 1975:Q1 to 2015:Q4. The construction follows Liu (2011) and, unless otherwise stated, the mnemonic pertains to FRED. The following six series were used;

1. Real house prices ($Qh = \frac{CSUSHPISA}{CONSDEF}$)

   The S&P/Case-Shiller U.S. National Home Price Index (**CSUSHPISA**) was divided by the deflator for personal consumption expenditure on non-durable Goods and personal consumption expenditure on services (**CONSDEF**).

2. Relative price of capital ($Qk = \frac{CONSDEF}{INVDEF}$)

   The deflator for personal consumption expenditure on non-durable goods and personal consumption expenditure on services (**CONSDEF**) was divided by the investment deflator (**INVDEF**).

3. Real consumption per capita ($C = \frac{PCND * CONSDEF}{CNP16OV}$)

   Personal consumption expenditure on non-durable goods (**PCND**) multiplied by the aforementioned deflator (**CONSDEF**) divided by civilian non-institutional population (**CNP16OV**).

4. Real Investment per capita ($I = \frac{(PCDG+PNFI)/CONSDEF}{CNP16OV}$)

Personal consumption expenditures on durables (**PCDG**) plus private non-residential investment (**PNFI**) divided by the deflator (**CONSDEF**), again divided by the civilian non-institutional population (**CNP16OV**).

5. Real non-financial business debt ($\frac{TLBSNNCB/CONSDEF}{CNP16OV}$)

   Non-financial business debt (**TLBSNNCB**) divided by the deflator (**CONSDEF**), again divided by the civilian non-institutional population (**CNP16OV**).

6. Real household debt ($\frac{CMDEBT/CONSDEF}{CNP16OV}$)

   Household and non-profit organisation debt (**CMDEBT**) divided by the deflator (**CONSDEF**), again divided by the civilian non-institutional population (**CNP16OV**).

All indices were rebased so that 2000:Q1=100. The data series were all non-stationary and so have been filtered using the one-sided HP filter.[14]

[14]For a discussion on the choice of this filtering method, see Pfiefer (2017) "A Guide to Specifying Observation Equations for the Estimation of DSGE Models.

3.D Appendix D - Estimation Plots

Bayesian impulse responses

Figure 3.9: Bayesian IRF: Tech Shock

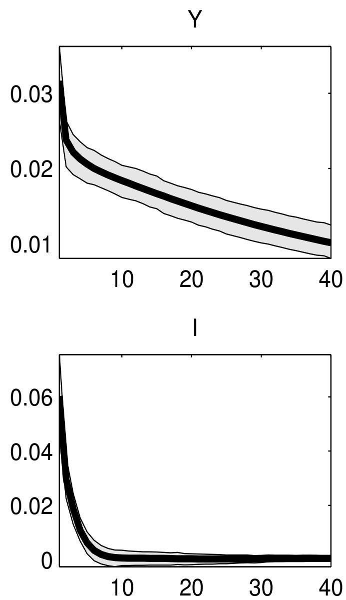


Figure 3.10: Bayesian IRF: Monetary Policy Shock

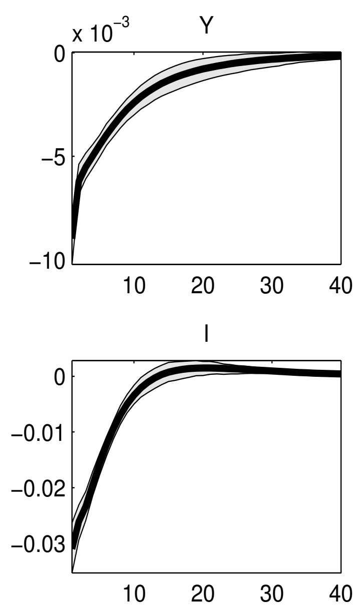


Figure 3.11: Bayesian IRF: Bank Capital Quality Shock

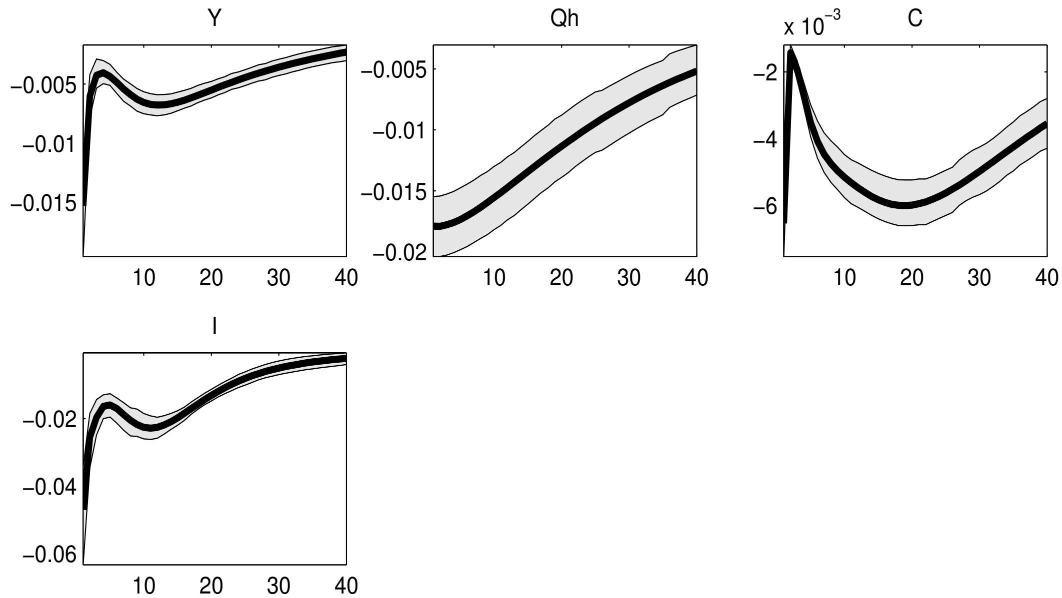


Figure 3.12: Bayesian IRF: Housing Preference Shock

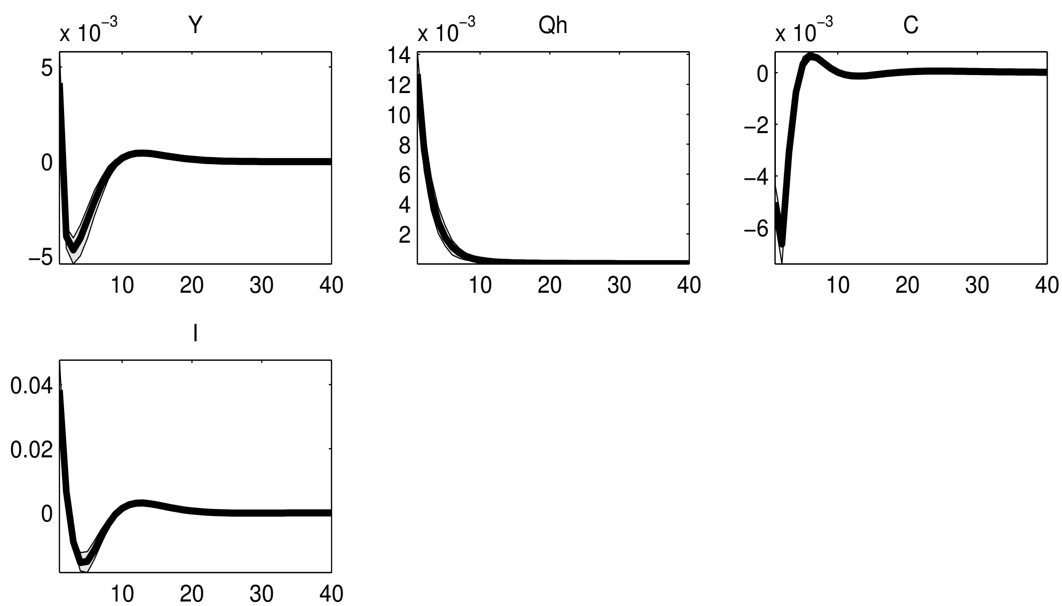


Figure 3.13: Bayesian IRF: LTV Shock

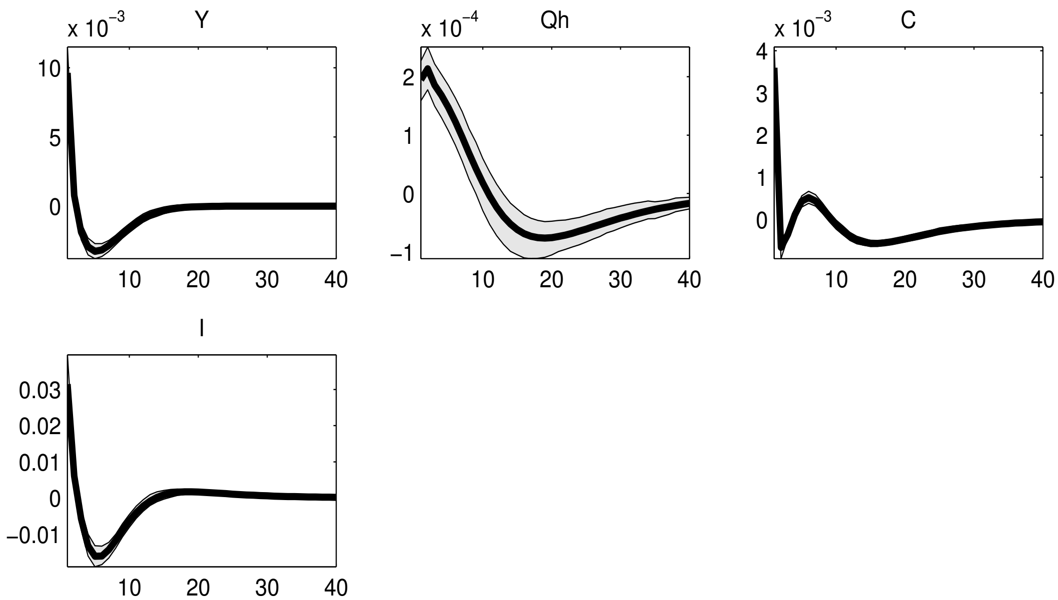


Figure 3.14: Mode Check Plot 1

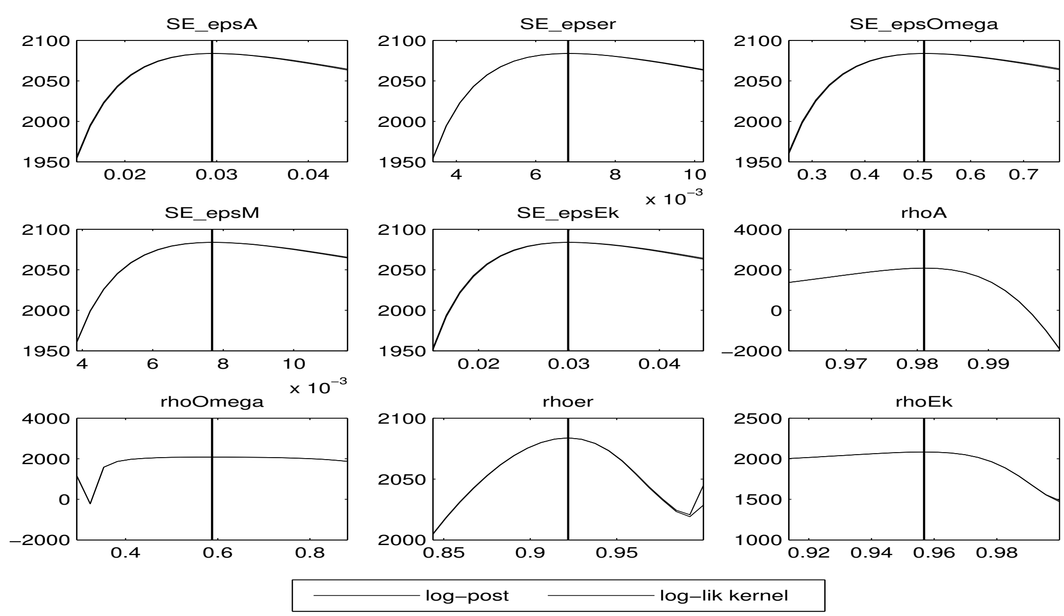


Figure 3.15: Mode Check Plot 2

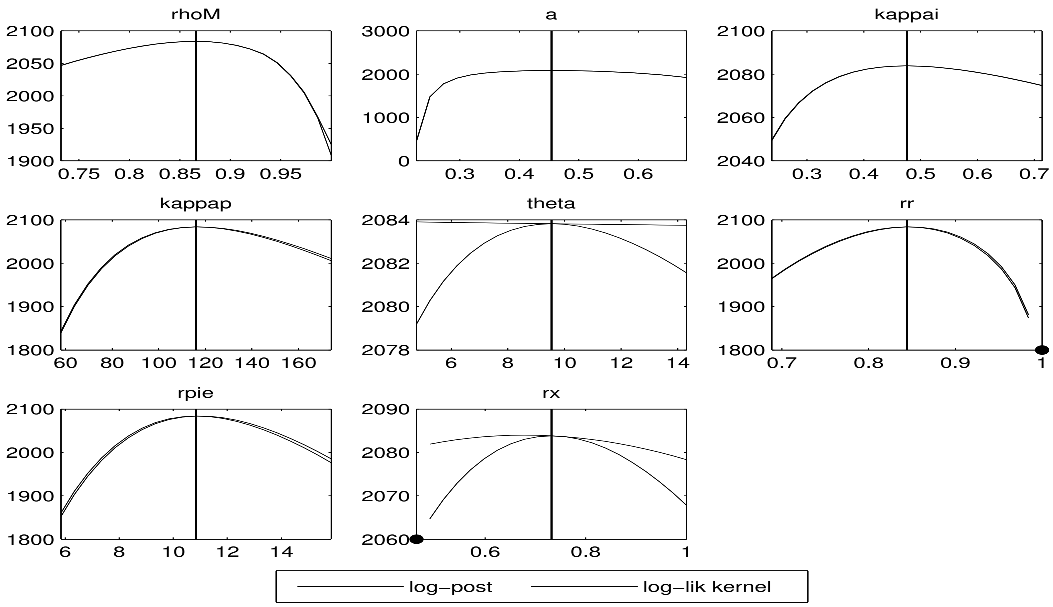


Figure 3.16: Priors and Posteriors Plot 1

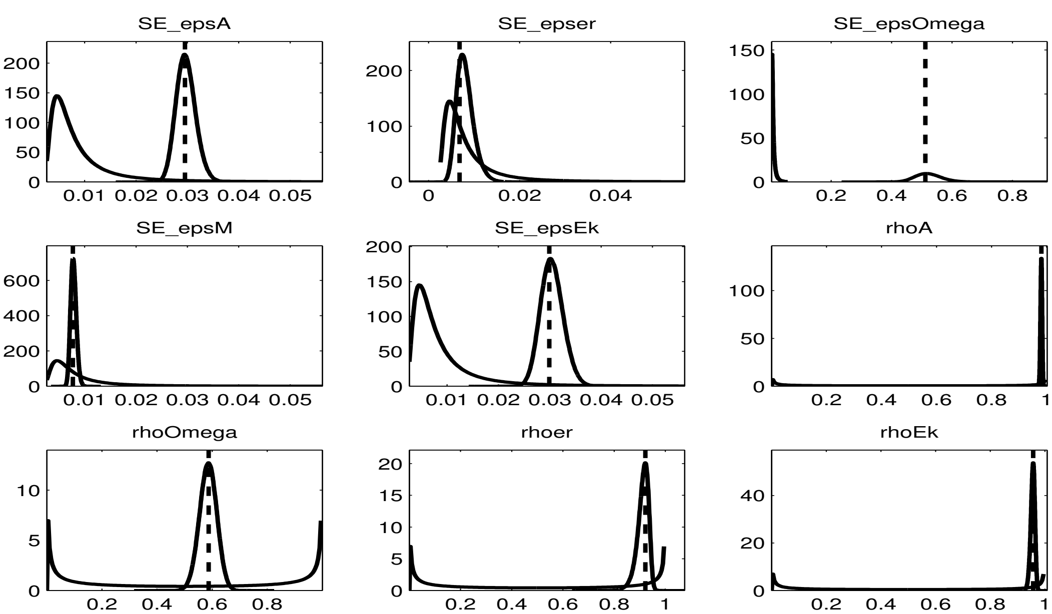


Figure 3.17: Priors and Posteriors Plot 2

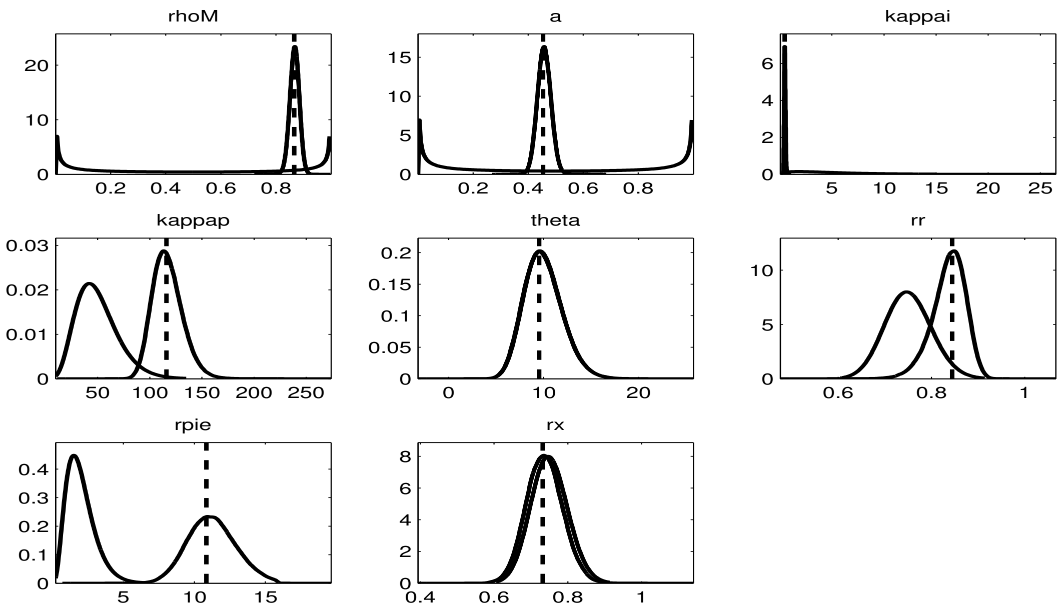


Figure 3.18: Smoothed Shocks

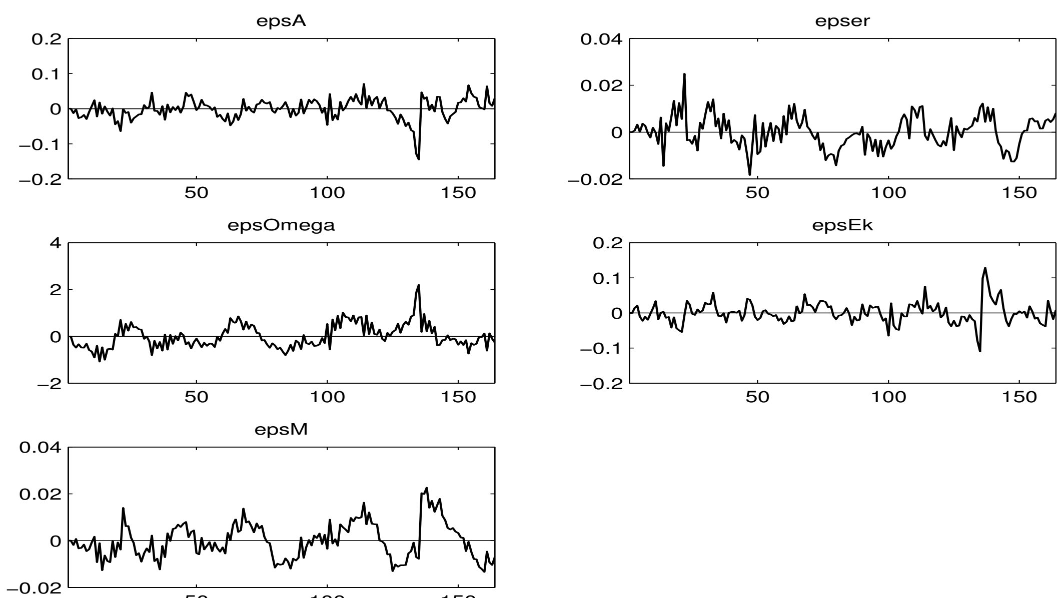


Figure 3.19: Smoothed Variables

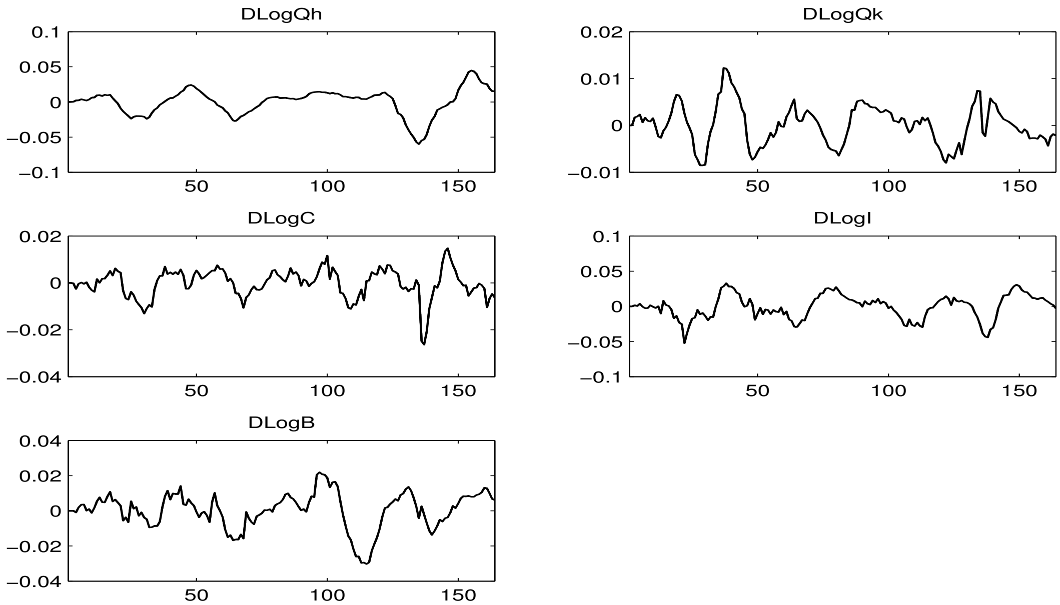
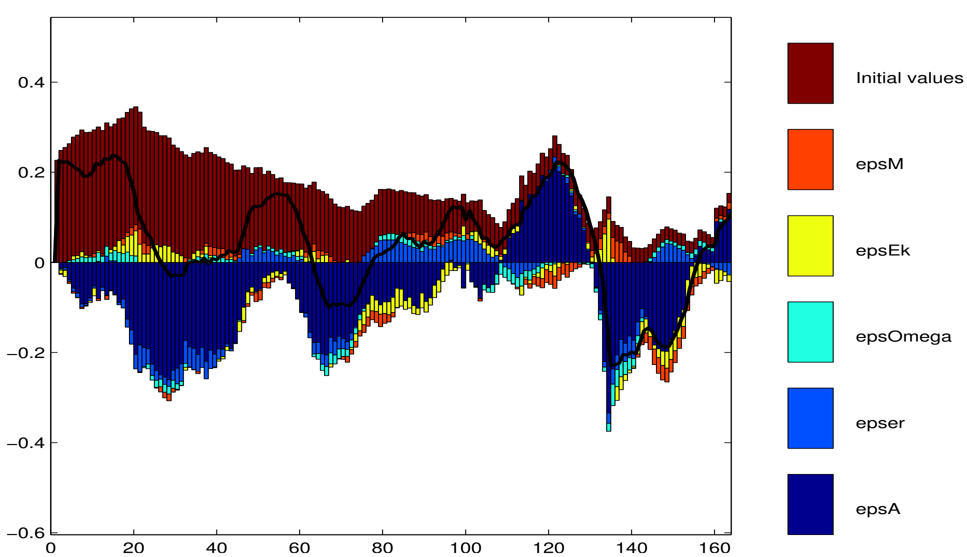


Figure 3.20: Variance Decomposition: Output



Note: initial values do not fall away particularly quickly. This means that deviations from the steady state are not well explained by the smoothed shocks above, implying the initial unknown value of state variables is having a considerable impact on the decomposition of output into the relative shocks.

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