House Prices, Credit Growth, and Excess Volatility: Implications for Monetary and Macroprudential Policy*

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Abstract

Progress on the question of whether policymakers should respond directly to financial variables requires a realistic economic model that captures the links between asset prices, credit expansion, and real economic activity. Standard DSGE models with fully-rational expectations have difficulty producing large swings in house prices and household debt that resemble the patterns observed in many developed countries over the past decade. We introduce excess volatility into an otherwise standard DSGE model by allowing a fraction of households to depart from fully-rational expectations. Specifically, we show that the introduction of simple moving-average forecast rules for a subset of households can significantly magnify the volatility and persistence of house prices and household debt relative to otherwise similar model with fully-rational expectations. We evaluate various policy actions that might be used to dampen the resulting excess volatility, including a direct response to house price growth or credit growth in the central bank's interest rate rule, the imposition of more restrictive loan-to-value ratios, and the use of a modified collateral constraint that takes into account the borrower's loan-to-income ratio. Of these, we find that a loan-to-income constraint is the most effective tool for dampening overall excess volatility in the model economy. We find that while an interest-rate response to house price growth or credit growth can stabilize some economic variables, it can significantly magnify the volatility of others, particularly inflation.

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1 Introduction

Household leverage in many industrial countries increased dramatically in the years prior to 2007. Countries with the largest increases in household debt relative to income tended to experience the fastest run-ups in house prices over the same period. The same countries tended to experience the most severe declines in consumption once house prices started falling (Glick and Lansing 2010, International Monetary Fund 2012).[1] Within the United States, house prices during the boom years of the mid-2000s rose faster in areas where subprime and exotic mortgages were more prevalent (Mian and Sufi 2009, Pavlov and Wachter 2011). In a given area, past house price appreciation had a significant positive influence on subsequent loan approval rates (Goetzmann et al. 2012). Areas which experienced the largest run-ups in household leverage tended to experience the most severe recessions as measured by the subsequent fall in durables consumption or the subsequent rise in the unemployment rate (Mian and Sufi 2010). Overall, the data suggests the presence of a self-reinforcing feedback loop in which an influx of new homebuyers with access to easy mortgage credit helped fuel an excessive run-up in house prices. The run-up, in turn, encouraged lenders to ease credit further on the assumption that house prices would continue to rise. Recession severity in a given area appears to reflect the degree to which prior growth in that area was driven by an unsustainable borrowing trend—one which came to an abrupt halt once house prices stopped rising (Mian and Sufi 2012).

Figure 1 illustrates the simultaneous boom in U.S. real house prices and per capita real household debt that occurred during the mid-2000s. During the boom years, per capita real GDP remained consistently above trend. At the time, many economists and policymakers argued that the strength of the U.S. economy was a fundamental factor supporting house prices. However, it is now clear that much of the strength of the economy during this time was linked to the housing boom itself. Consumers extracted equity from appreciating home values to pay for all kinds of goods and services while hundreds of thousands of jobs were created in residential construction, mortgage banking, and real estate. After peaking in 2006, real house prices have retraced to the downside while the level of real household debt has started to decline. Real GDP experienced a sharp drop during the Great Recession and remains about 5% below trend. Other macroeconomic variables also suffered severe declines, including per capita real consumption and the employment-to-population ratio.[2]

The unwinding of excess household leverage via higher saving or increased defaults is

[1] King (1994) identified a similar correlation between prior increases in household leverage and the severity of the early 1990s recession using data for ten major industrial countries from 1984 to 1992. He also notes that U.S. consumer debt more than doubled during the 1920s—a factor that likely contributed to the severity of the Great Depression in the early 1930s.

[2] For details, see Lansing (2011).

imposing a significant drag on consumer spending and bank lending in many countries, thus hindering the vigor of the global economic recovery.[3] In the aftermath of the global financial crisis and the Great Recession, it is important to consider what lessons might be learned for the conduct of policy. Historical episodes of sustained rapid credit expansion together with booming stock or house prices have often signaled threats to financial and economic stability (Borio and Lowe 2002). Times of prosperity which are fueled by easy credit and rising debt are typically followed by lengthy periods of deleveraging and subdued growth in GDP and employment (Reinhart and Reinhart 2010). According to Borio and Lowe (2002) "If the economy is indeed robust and the boom is sustainable, actions by the authorities to restrain the boom are unlikely to derail it altogether. By contrast, failure to act could have much more damaging consequences, as the imbalances unravel." This point raises the question of what "actions by authorities" could be used to restrain the boom? Our goal in this paper is to explore the effects of various policy measures that might be used to lean against credit-fueled financial imbalances.

Standard DSGE models with fully-rational expectations have difficulty producing large swings in house prices and household debt that resemble the patterns observed in many developed countries over the past decade. Indeed, it is common for such models to include highly persistent exogenous shocks to rational agents' preferences for housing in an effort to bridge the gap between the model and the data.[4] If housing booms and busts were truly driven by preference shocks, then central banks would seem to have little reason to be concerned about them. Declines in the collateral value of an asset are often modeled as being driven by exogenous fundamental shocks to the "quality" of the asset, rather than the result of a burst asset price bubble.[5] Kocherlakota (2009) remarks: "The sources of disturbances in macroeconomic models are (to my taste) patently unrealistic...I believe that [macroeconomists] are handicapping themselves by only looking at shocks to fundamentals like preferences and technology. Phenomena like credit market crunches or asset market bubbles rely on self-fulfilling beliefs about what others will do." These ideas motivate consideration of a model where agents' subjective forecasts serve as an endogenous source of volatility.

We use the term "excess volatility" to describe a situation where macroeconomic variables move too much to be explained by a rational response to fundamentals. Numerous empirical studies starting with Shiller (1981) and LeRoy and Porter (1981) have shown that stock prices

[3] See, for example, Roxburgh, et al. (2012).

[4] Examples include Iacoviello (2005), Iacoviello and Neri (2010), and Walentin and Sellin (2010).

[5] See, for example, Gertler et al. (2012) in which a financial crisis is triggered by an exogenous "disaster shock" that wipes out a fraction of the productive capital stock. Similarly, a model-based study by the International Monetary Fund (2009) states that (p. 110) "Although asset booms can arise from expectations...without any change in fundamentals, we do not model bubbles or irrational exuberence." Gilchrist and Leahy (2002) examine the response of monetary policy to asset prices in a rational expectations model with exogenous "net worth shocks."

appear to exhibit excess volatility when compared to the discounted stream of ex post realized dividends.[6] Similarly, Campbell et al. (2009) find that movements in U.S. house price-rent ratios cannot be fully explained by movements in future rent growth.

We introduce excess volatility into an otherwise standard DSGE model by allowing a fraction of households to depart from fully-rational expectations. Specifically, we show that the introduction of simple moving-average forecast rules, i.e., adaptive expectations, for a subset of households can significantly magnify the volatility and persistence of house prices and household debt relative to otherwise similar model with fully-rational expectations. As shown originally by Muth (1960), a moving-average forecast rule with exponentially-declining weights on past data will coincide with rational expectations when the forecast variable evolves as a random walk with permanent and temporary shocks. Such a forecast rule can be viewed as boundedly-rational because it economizes on the costs of collecting and processing information. As noted by Nerlove (1983, p. 1255): "Purposeful economic agents have incentives to eliminate errors up to a point justified by the costs of obtaining the information necessary to do so...The most readily available and least costly information about the future value of a variable is its past value."[7]

The basic structure of the model is similar to Iacoviello (2005) with two types of households. Patient-lender households own the entire capital stock and operate monopolistically-competitive firms. Impatient-borrower households derive income only from labor and face a borrowing constraint linked to the market value of their housing stock. Expectations are modeled as a weighted-average of a fully-rational forecast rule and a moving-average forecast rule. We calibrate the parameters of the hybrid expectations model to generate an empirically plausible degree of volatility in the simulated house price and household debt series. Our setup implies that 30% of households employ a moving-average forecast rule while the remaining 70% are fully-rational.[8] Due to the self-referential nature of the model's equilibrium conditions, the unit root assumption embedded in the moving-average forecast rule serves to magnify the volatility of endogenous variables in the model. Our setup captures the idea that much of the run-up in U.S. house prices and credit during the boom years was linked to the influx of an unsophisticated population of new homebuyers.[9] Given their inexperience, these buyers would be more likely to employ simple forecast rules about future house prices, income, etc.

[6] Lansing and LeRoy (2012) provide a recent update on this literature.

[7] An empirical study by Chow (1989) finds that an asset pricing model with adaptive expectations outperforms one with rational expectations in accounting for observed movements in U.S. stock prices and interest rates.

[8] Using U.S. data over the period 1981 to 2006, Levin et al. (2012) estimate that around 65 to 80 percent of agents employ moving-average forecast rules in the context of DSGE model which omits house prices and household debt.

[9] See Mian and Sufi (2009) and Chapter 6 of the report of the U.S. Financial Crisis Inquiry Commission (2011), titled "Credit Expansion."

Figure 2 shows that house price forecasts derived from the futures market for the Case-Shiller house price index (which are only available from 2006 onwards) often exhibit a series of one-sided forecast errors. The futures market tends to overpredict future house prices when prices are falling—a pattern that is consistent with a moving-average forecast rule. Similarly, Figure 3 shows that U.S. inflation expectations derived from the Survey of Professional Forecasters tend to systematically underpredict subsequent actual inflation in the sample period prior to 1979 when inflation was rising and systematically overpredict it thereafter when inflation was falling. Rational expectations would not give rise to such a sustained sequence of one-sided forecast errors.[10]

The volatilities of house prices and household debt in the hybrid expectations model are about two times larger than those in the rational expectations model. Both variables exhibit higher persistence under hybrid expectations. Stock price volatility is magnified by a factor of about 1.3, whereas the volatilities of output, labor hours, inflation, and consumption are magnified by factors ranging from 1.1 to 1.9. These results are striking given that only 30% of households in the model employ moving-average forecast rules. The use of moving-average forecast rules by even a small subset of agents can have a large influence on model dynamics because the presence of these agents also influences the nature of the fully-rational forecast rules employed by the remaining agents.

Given the presence of excess volatility, we evaluate various policy actions that might be used to dampen the observed fluctuations. With regard to monetary policy, we consider a direct response to either house price growth or credit growth in the central bank's interest rate rule. With regard to macroprudential policy, we consider the imposition of a more restrictive loan-to-value ratio (i.e., a tightening of lending standards) and the use of a modified collateral constraint that takes into account the borrower's loan-to-income ratio. Of these, we find that a loan-to-income constraint is the most effective tool for dampening overall excess volatility in the model economy. We find that while an interest-rate response to house price growth or credit growth can stabilize some economic variables, it can significantly magnify the volatility of others, particularly inflation.

Our results for an interest rate response to house price growth show some benefits under rational expectations (lower volatilities for household debt and consumption) but the benefits under hybrid expectations are less pronounced. Under both expectation regimes, inflation volatility is magnified with the effect being particularly severe under hybrid expectations. Such results are unsatisfactory from the standpoint of an inflation-targeting central bank that seeks to minimize a weighted-sum of squared deviations of inflation and output from target

[10] Numerous studies document evidence of bias and inefficiency in survey forecasts of U.S. inflation. See, for example, Roberts (1997), Mehra (2002), Carroll (2003), and Mankiw, Reis, and Wolfers (2004). More recently, Coibion and Gorodnichenko (2012) find robust evidence against full-information rational expectations in survey forecasts for U.S. inflation and unemployment.

values. Indeed we show that the value of a typical central bank loss function rises monotonically as more weight in placed on house price growth in the interest rate rule.

The results for an interest rate response to credit growth also show some benefits under rational expectations. However, these benefits mostly disappear under hybrid expectations. Moreover, the undesirable magnification of inflation volatility becomes much worse. The results for this experiment demonstrate that the effects of a particular monetary policy can be influenced by the nature of agents' expectations.[11] We note that Christiano, et al. (2010) find that a strong interest-rate response to credit growth can improve the welfare of a representative household in a rational expectations model with news shocks. Such results could be sensitive to their assumption of fully-rational expectations.

Turning to macroprudential policy, we find that a reduction in the loan-to-value ratio from 0.7 to 0.5 substantially reduces the volatility of household debt under both expectations regimes, but the volatility of most other variables are slightly magnified by factors ranging from 1.01 to 1.08. The volatility of aggregate consumption and aggregate labor hours are little changed. For policymakers, these mixed stabilization results must be weighed against the drawbacks of permanently restricting household access to borrowed money which helps impatient households smooth their consumption. In the sensitivity analysis, we find that an *increase* in the loan-to-value ratio (implying looser lending standards) reduces the volatility of aggregate consumption and aggregate labor hours but it significantly magnifies the volatility of household debt. A natural alternative to a permanent change in the loan-to-value ratio is to shift the ratio in a countercyclical manner without changing its steady-state value. A number of papers have identified stabilization benefits from the use of countercyclical loan-to-value rules in rational expectations models.[12]

Our final policy experiment achieves a countercyclical loan-to-value ratio in a novel way by requiring lenders to place a substantial weight on the borrower's wage income in the borrowing constraint. As the weight on the borrower's wage income increases, the generalized borrowing constraint takes on more of the characteristics of a loan-to-income constraint. Intuitively, a loan-to-income constraint represents a more prudent lending criterion than a loan-to-value constraint because income, unlike asset value, is less subject to distortions from bubble-like movements in asset prices. Figure 4 shows that during the U.S. housing boom of the mid-2000s, loan-to-value measures did not signal any significant increase in household leverage because the value of housing assets rose together with liabilities. Only after the collapse of house prices did the loan-to-value measures provide an indication of excessive household leverage. But by

[11] Orphanides and Williams (2009) make a related point. They find that an optimal control policy derived under the assumption of perfect knowledge about the structure of the economy can perform poorly when knowledge is imperfect.

[12] See, for example, Kannan, Rabanal and Scott (2009), Angelini, Neri, and Panetta (2010), Christensen and Meh (2011), and Lambertini, Mendicino and Punzi (2011).

then, the over-accumulation of household debt had already occurred.[13] By contrast, the ratio of U.S. household debt to disposable personal income started to rise rapidly about five years earlier, providing regulators with a more timely warning of a potentially dangerous buildup of household leverage.

We show that the generalized borrowing constraint serves as an "automatic stabilizer" by inducing an endogenously countercyclical loan-to-value ratio. In our view, it is much easier and more realistic for regulators to simply mandate a substantial emphasis on the borrowers' wage income in the lending decision than to expect regulators to frequently adjust the maximum loan-to-value ratio in a systematic way over the business cycle or the financial/credit cycle.[14] For the generalized borrowing constraint, we impose a weight of 50% on the borrower's wage income with the remaining 50% on the expected value of housing collateral. The multiplicative parameter in the borrowing constraint is adjusted to maintain the same steady-state loan-to value ratio as in the baseline model. Under hybrid expectations, the generalized borrowing constraint substantially reduces the volatility of household debt, while mildly reducing the volatility of other key variables, including output, labor hours, inflation, and consumption. Notably, the policy avoids the large undesirable magnification of inflation volatility that is observed in the two interest rate policy experiments.

Comparing across the various policy experiments, the generalized borrowing constraint appears to be the most effective tool for dampening overall excess volatility in the model economy. The value of a typical central bank loss function declines monotonically (albeit slightly) as more weight is placed on the borrower's wage income in the borrowing constraint. The beneficial stabilization results of this policy become more dramatic if the loss function is expanded to take into account the variance of household debt. The expanded loss function can be interpreted as reflecting a concern for financial stability. Specifically, the variance of household debt captures the idea that historical episodes of sustained rapid credit expansion have often led to crises and severe recessions.[15] Recently, the Committee on International Economic and Policy Reform (2011) has called for central banks to go beyond their traditional emphasis on flexible inflation targeting and adopt an explicit goal of financial stability. Similarly, Woodford (2011) argues for an expanded central bank loss function that reflects a concern for financial stability. In his model, this concern is linked to a variable that measures financial sector leverage.

[13] In a speech in February 2004, Fed Chairman Alan Greenspan remarked "Overall, the household sector seems to be in good shape, and much of the apparent increase in the household sector's debt ratios over the past decade reflects factors that do not suggest increasing household financial stress."

[14] Drehmann et al. (2012) employ various methods for distinguishing the business cycle from the financial or credit cycle. They argue that the financial cycle is much longer than the traditional business cycle.

[15] Akram and Eitrheim (2008) investigate different ways of representing a concern for financial stability in a reduced-form econometric model. Among other metrics, they consider the standard deviation of the debt-to-income ratio and the standard deviation of the debt service-to-income ratio.

1.1 Related Literature

An important unsettled question in economics is whether policymakers should take deliberate steps to prevent or deflate asset price bubbles.[16] History suggests that bubbles can be extraordinarily costly when accompanied by significant increases in borrowing. On this point, Irving Fisher (1930, p. 341) famously remarked, "[O]ver-investment and over-speculation are often important, but they would have far less serious results were they not conducted with borrowed money." Unlike stocks, the typical residential housing transaction is financed almost entirely with borrowed money. The use of leverage magnifies the contractionary impact of a decline in asset prices. In a study of 21 advanced economies from 1970 to 2008, the International Monetary Fund (2009) found that housing-bust recessions tend to be longer and more severe than stock-bust recessions.

Early contributions to the literature on monetary policy and asset prices (Bernanke and Gertler 2001, Cecchetti, al. 2002) employed models in which bubbles were wholly exogenous, i.e., bubbles randomly inflate and contract regardless of any central bank action. Consequently, these models cannot not address the important questions of whether a central bank should take deliberate steps to prevent bubbles from forming or whether a central bank should try to deflate a bubble once it has formed. In an effort to address these shortcomings, Filardo (2008) develops a model where the central bank's interest rate policy can influence the transition probability of a stochastic bubble. He finds that the optimal interest rate policy includes a response to asset price growth.

Dupor (2005) considers the policy implications of non-fundamental asset price movements which are driven by exogenous "expectation shocks." He finds that optimal monetary policy should lean against non-fundamental asset price movements. Gilchrist and Saito (2008) find that an interest-rate response to asset price growth is helpful in stabilizing an economy with rational learning about unobserved shifts in the economy's stochastic growth trend. Airaudo et al. (2012) find that an interest-rate response to stock prices can stabilize an economy against sunspot shocks in a rational expectations model with multiple equilibria. Our analysis differs from these papers in that we allow a subset agents to depart from fully-rational expectations. We find that the nature of agents' expectations can influence the benefits of an interest rate rule that responds to house price growth or credit growth.

Some recent research that incorporates moving-average forecast rules or adaptive expectations into otherwise standard models include Sargent (1999, Chapter 6), Lettau and Van Zandt (2003), Evans and Ramey (2006), Lansing (2009), and Huang et. al (2009), among others. Lansing (2009) shows that survey-based measures of U.S. inflation expectations are well-captured by a moving average of past realized inflation rates. Huang et al. (2009) con-

[16] For an overview of the various arguments, see Lansing (2008).

clude that "adaptive expectations can be an important source of frictions that amplify and propagate technology shocks and seem promising for generating plausible labor market dynamics."

Constant-gain learning algorithms of the type described by Evans and Honkapoja (2001) are similar in many respects to adaptive expectations; both formulations assume that agents apply exponentially-declining weights to past data when constructing forecasts of future variables.[17] Orphanides and Williams (2005), Milani (2007), and Eusepi and Preston (2011) all find that adaptive learning models are more successful than rational expectations models in capturing several quantitative properties of U.S. macroeconomic data.

Adam, Kuang and Marcet (2012) show that the introduction of constant-gain learning in a small open economy can help account for recent cross-country patterns in house prices and current account dynamics. Granziera and Kozicki (2012) show that a simple Lucas-type asset pricing model with extrapolative expectations can match the run-up in U.S. house prices from 2000 to 2006 as well as the subsequent sharp downturn.[18] Finally, De Grauwe (2012) shows that the introduction of endogenous switching between two types of simple forecasting rules in a New Keynesian model can generate excess kurtosis in the simulated output gap, consistent with U.S. data.

2 The Model

The basic structure of the model is similar to Iacoviello (2005). The economy is populated by two types of households: *patient* (indexed by $j = 1$) and *impatient* (indexed by $j = 2$), of mass $1 - n$ and n, respectively. Impatient households have a lower subjective discount factor ($\beta_2 < \beta_1$) which generates an incentive for them to borrow. Nominal price stickiness is assumed in the consumption goods sector. Monetary policy follows a standard Taylor-type interest rate rule.

2.1 Households

Households derive utility from a flow of consumption $c_{j,t}$ and services from housing $h_{j,t}$. They derive disutility from labor $L_{j,t}$. Each household maximizes

$$\widehat{E}_{j,t} \sum_{t=0}^{\infty} \beta_j^t \left\{ \log\left(c_{j,t} - b c_{j,t-1}\right) + \nu_{j,h} \log\left(h_{j,t}\right) - \nu_{j,L} \frac{L_{j,t}^{1+\varphi_L}}{1+\varphi_L} \right\}, \tag{1}$$

[17] Along these lines, Sargent (1996, p.543) remarks "[A]daptive expectations has made a comeback in other areas of theory, in the guise of non-Bayesian theories of learning."

[18] Survey data from both stock and real estate markets suggest the presence of extrapolative expectations among investors. For a summary of the evidence, see Jurgilas and Lansing (2012).

where the symbol $\widehat{E}_{j,t}$ represents the subjective expectation of household type j, conditional on information available time t, as explained more fully below. Under rational expectations, $\widehat{E}_{j,t}$ corresponds to the mathematical expectation operator E_t evaluated using the objective distributions of the stochastic shocks, which are assumed known by the rational household. The parameter b governs the importance of habit formation in utility, where $c_{j,t-1}$ is a reference level of consumption which the household takes into account when formulating its optimal consumption plan. The parameter $\nu_{j,h}$ governs the utility from housing services, $\nu_{j,L}$ governs the disutility of labor supply, and φ_L governs the elasticity of labor supply. The total housing stock is fixed such that $(1-n)\, h_{1,t} + nh_{2,t} = 1$ for all t.

Impatient Borrowers. Impatient-borrower households maximize utility subject to the budget constraint:

$$c_{2t} + q_t(h_{2,t} - h_{2,t-1}) + \frac{b_{2,t-1}R_{t-1}}{\pi_t} = b_{2,t} + w_t L_{2,t}, \tag{2}$$

where R_{t-1} is the gross nominal interest rate at the end of period $t-1$, $\pi_t \equiv P_t/P_{t-1}$ is the gross inflation rate during period t, w_t is the real wage, q_t is the real price of housing, and $b_{2,t-1}$ is the borrower's real debt at the end of period $t-1$.

New borrowing during period t is constrained in that impatient households may only borrow (principle and interest) up to a fraction of the expected value of their housing stock in period $t+1$:

$$b_{2,t} \;\leq\; \frac{\gamma}{R_t}\left[\widehat{E}_{1,t}\, q_{t+1}\pi_{t+1}\right] h_{2,t}\,, \tag{3}$$

where $0 \leq \gamma \leq 1$ represents the loan-to-value ratio and $\widehat{E}_{1,t}\, q_{t+1}\pi_{t+1}$ represents the lender's subjective forecast of future variables that govern the collateral value and the real interest rate burden of the loan.

The impatient household's optimal choices are characterized by the following first-order conditions:

$$-U_{L_{2,t}} = U_{c_{2,t}} w_t, \tag{4}$$

$$U_{c_{2,t}} - \mu_t = \beta_2 R_t \widehat{E}_{2,t}\left[\frac{U_{c_{2,t+1}}}{\pi_{t+1}}\right], \tag{5}$$

$$U_{h_{2,t}} + \beta_2 \widehat{E}_{2,t}\left[U_{c_{2,t+1}} q_{t+1}\right] + \mu_t \frac{\gamma}{R_t}\widehat{E}_{1,t}\left[q_{t+1}\pi_{t+1}\right] = U_{c_{2,t}} q_t, \tag{6}$$

where μ_t is the Lagrange multiplier associated with the borrowing constraint.[19]

Patient Lenders. Patient-lender households choose how much to consume, work, invest in housing, and invest in physical capital k_t which is rented to firms at the rate r_t^k. They also

[19] Given that $\beta_2 < \beta_1$, it is straightforward to show that equation (3) holds with equality at the deterministic steady state. As is common in the literature, we solve the model assuming that the constraint is binding in a neighbourhood around the steady state. See, for example, Iacoviello (2005) and Iacoviello and Neri (2010).

receive the firm's profits ϕ_t and make one-period loans to borrowers. The budget constraint of the patient household is given by:

$$c_{1,t} + I_t + q_t(h_{1,t} - h_{1,t-1}) + \frac{b_{1,t-1}R_{t-1}}{\pi_t} = b_{1,t} + w_t L_{1,t} + r_t^k k_{t-1} + \phi_t, \tag{7}$$

where $(1-n)\, b_{1,t-1} = -nb_{2,t-1}$ in equilibrium. In other words, the aggregate bonds of patient households correspond to the aggregate loans of impatient households.

The law of motion for physical capital is given by:

$$k_t = (1-\delta)k_{t-1} + [1 - \underbrace{\tfrac{\psi}{2}\left(I_t/I_{t-1} - 1\right)^2}_{S(I_t/I_{t-1})}]\, I_t, \tag{8}$$

where δ is the depreciation rate and the function $S\left(I_t/I_{t-1}\right)$ reflects investment adjustment costs. In steady state $S\left(\cdot\right) = S'\left(\cdot\right) = 0$ and $S''\left(\cdot\right) > 0$.

The patient household's optimal choices are characterized by the following first-order conditions:

$$-U_{L_{1,t}} = U_{c_{1,t}} w_t, \tag{9}$$

$$U_{c_{1,t}} = \beta_1 R_t \widehat{E}_{1,t}\left[\frac{U_{c_{1,t+1}}}{\pi_{t+1}}\right], \tag{10}$$

$$U_{c_{1,t}} q_t = U_{h_{1,t}} + \beta_1 \widehat{E}_{1,t}\left[U_{c_{1,t+1}} q_{t+1}\right], \tag{11}$$

$$U_{c_{1t}} q_t^k = \beta_1 \widehat{E}_{1,t}\left\{U_{c_{1,t+1}}\left[q_{t+1}^k(1-\delta) + r_{t+1}^k\right]\right\}, \tag{12}$$

$$U_{c_{1,t}} = U_{c_{1,t}} q_t^k \left[1 - S\left(\tfrac{I_t}{I_{t-1}}\right) - \tfrac{I_t}{I_{t-1}} S'\left(\tfrac{I_t}{I_{t-1}}\right)\right] + \left(\tfrac{I_t}{I_{t-1}}\right)^2 \beta_1 \widehat{E}_{1,t}\left[U_{c_{1,t+1}} q_{t+1}^k S'\left(\tfrac{I_{t+1}}{I_t}\right)\right], \tag{13}$$

where the last two equations represent the optimal choices of k_t and I_t, respectively. The symbol $q_t^k \equiv \upsilon_t / U_{c_{1t}}$ is the relative marginal value of installed capital with respect to consumption, where υ_t is the Lagrange multiplier associated with the capital law of motion (8). We interpret q_t^k as the market value of claims to physical capital, i.e., the stock price.

2.2 Firms and Price Setting

Firms are owned by the patient households. Hence, we assume that the subjective expectations of firms are formulated in the same way as their owners.

Final Good Production. There is a unique final good y_t that is produced using the following constant returns-to-scale technology:

$$y_t = \left[\int_0^1 y_t(i)^{\frac{\theta-1}{\theta}} di\right]^{\frac{\theta}{\theta-1}}, \quad i \in [0,1], \tag{14}$$

where the inputs are a continuum of intermediate goods $y_t(i)$ and $\theta > 1$ is the constant elasticity-of-substitution across goods. The price of each intermediate good $P_t(i)$ is taken as given by the firms. Cost minimization implies the following demand function for each good $y_t(i) = [P_t(i)/P_t]^{-\theta} y_t$, where the price index for the intermediate good is given by $P_t = \left[\int_0^1 P_t(i)^{1-\theta} di\right]^{1/(1-\theta)}$.

In the wholesale sector, there is a continuum of firms indexed by $i \in [0,1]$ and owned by patient households. Intermediate goods-producing firms act in a monopolistic market and produce $y_t(i)$ units of each intermediate good i using $L_t(i) = (1-n)\, L_{1,t}(i) + nL_{2,t}(i)$ units of labor, according to the following constant returns-to-scale technology:

$$y_t(i) = \exp(z_t)\, k_t(i)^{\alpha} L_t(i)^{1-\alpha}, \tag{15}$$

where z_t is an AR(1) productivity shock.

Intermediate Good Production. We assume that intermediate firms adjust the price of their differentiated goods following the Calvo (1983) model of staggered price setting. Prices are adjusted with probability $1-\theta_\pi$ every period, leading to the following New Keynesian Phillips curve:

$$\log\left(\tfrac{P_t}{P_{t-1}}\right) - \iota_\pi \log\left(\tfrac{P_{t-1}}{P_{t-2}}\right) = \beta\left[\widehat{E}_{1,t} \log\left(\tfrac{P_{t+1}}{P_t}\right) - \iota_\pi \log\left(\tfrac{P_t}{P_{t-1}}\right)\right] - \kappa_\pi \log\left(\frac{s_t}{s}\right) + u_t \tag{16}$$

where $\kappa_\pi \equiv (1-\theta_\pi)(1-\beta\theta_\pi)/\theta_\pi$ and ι_π is the indexation parameter that governs the automatic price adjustment of non-optimizing firms. Variables without time subscripts represent steady-state values. The variable s_t represents the marginal cost of production and u_t is an AR(1) cost-push shock.

2.3 Monetary and Macroprudential Policy

In the baseline model, we assume that the central bank follows a simple Taylor-type rule of the form:

$$R_t = (1+r)\left(\frac{\pi_t}{1}\right)^{\alpha_\pi}\left(\frac{y_t}{y}\right)^{\alpha_y} \varsigma_t, \tag{17}$$

where R_t is the gross nominal interest rate, $r = 1/\beta_1 - 1$ is the steady-state real interest rate, $\pi_t \equiv P_t/P_{t-1}$ is the gross inflation rate, y_t/y is the proportional output gap, and ς_t is an AR(1) policy shock.

In the policy experiments, we consider the following generalized policy rule that allows for a direct response to either credit growth or house price growth:

$$R_t = (1+r)\left(\frac{\pi_t}{1}\right)^{\alpha_\pi}\left(\frac{y_t}{y}\right)^{\alpha_y}\left(\frac{q_t}{q_{t-4}}\right)^{\alpha_q}\left(\frac{b_{2,t}}{b_{2,t-4}}\right)^{\alpha_b} \varsigma_t, \tag{18}$$

where q_t/q_{t-4} is the 4-quarter growth rate in house prices (which equals the growth rate in the market value of the fixed housing stock) and $b_{2,t}/b_{2,t-4}$ is the 4-quarter growth rate of household debt, i.e., credit growth.

In the aftermath of the global financial crisis, a wide variety of macroprudential policy tools have been proposed to help ensure financial stability.[20] For our purposes, we focus on policy variables that appear in the collateral constraint. For our first macroprudential policy experiment, we allow the regulator to adjust the value of the parameter γ in equation (3). Lower values of γ imply tighter lending standards. In the second macroprudential policy experiment, we consider a generalized version of the borrowing constraint which takes the form

$$b_{2,t} \;\leq\; \frac{\widehat{\gamma}}{R_t}\left\{m\,w_t L_{2,t} \;+\; (1-m)\,\left[\widehat{E}_{1,t}\,q_{t+1}\pi_{t+1}\right]\,h_{2,t}\right\}, \tag{19}$$

where m is the weight assigned by the lender to the borrower's wage income. Under this specification, $m = 0$ corresponds to the baseline model where the lender only considers the expected value of the borrower's housing collateral.[21] We interpret changes in the value of m as being directed by the regulator. As m increases, the regulator directs the lender to place more emphasis on the borrower's wage income when making a lending decision. Whenever $m > 0$, we calibrate the value of the parameter $\widehat{\gamma}$ to maintain the same steady state loan-to-value ratio as in the baseline version of the constraint (3). In steady state, we therefore have $\widehat{\gamma} = \gamma/\left[m\,wL_2/\left(q\pi h_2\right) + 1 - m\right]$, where $\widehat{\gamma} = \gamma$ when $m = 0$. When $m > 0$, the equilibrium loan-to-value ratio is no longer constant but instead moves in the same direction as the ratio of the borrower's wage income to housing collateral value. Consequently, the equilibrium loan-to-value ratio will endogenously decline whenever the market value of housing collateral increases faster than the borrower's wage income. In this way, the generalized borrowing constraint acts like an automatic stabilizer to dampen fluctuations in household debt that are linked to excessive movements in house prices.

2.4 Expectations

Rational expectations are built on strong assumptions about households' information. In actual forecasting applications, real-time difficulties in observing stochastic shocks, together with empirical instabilities in the underlying shock distributions could lead to large and persistent forecast errors. These ideas motivate consideration of a boundedly-rational forecasting algorithm, one that requires substantially less computational and informational resources. A long

[20] Galati and Moessner (2011) and the Bank of England (2011) provide comprehensive reviews of this literature.

[21] The generalization of the borrowing constraint has an impact on the first-order conditions of the impatient households. In particular, the labor supply equation (4) is replaced by $-U_{L_{2t}} = w_t\left[U_{c_{2t}} + \,\widehat{\gamma}\,m\mu_t\right]$, where μ_t is the Lagrange multiplier associated with the generalized borrowing constraint.

history in macroeconomics suggests the following adaptive (or error-correction) approach:

$$
\begin{aligned}
F_t\, X_{t+1} &= F_{t-1}\, X_t \;+\; \lambda \left(X_t - F_{t-1}\, X_t \right), \qquad 0 < \lambda \leq 1, \\
&= \lambda \left[X_t + (1-\lambda)\; X_{t-1} + (1-\lambda)^2\; X_{t-2} + ... \right], \qquad (20)
\end{aligned}
$$

where X_{t+1} is the object to be forecasted and $F_t\, X_{t+1}$ is the corresponding forecast. In this model, X_{t+1} is typically a nonlinear combination of endogenous and exogenous variables dated at time $t+1$. For example, in equation (5) we have $X_{t+1} = U_{c_{2,t+1}}/\pi_{t+1}$, whereas in equation (12) we have $X_{t+1} = U_{c_{1,t+1}} \left[q^k_{t+1}(1-\delta) + r^k_{t+1} \right]$. The term $X_t - F_{t-1} X_t$ is the forecast error in period t. The parameter λ governs the response to the most recent observation X_t. For simplicity, we assume that λ is the same for both types of households.

Equation (20) implies that the forecast at time t is an exponentially-weighted moving average of past observed values of the forecast object, where λ governs the distribution of weights assigned to past values—analogous to the gain parameter in the adaptive learning literature. When $\lambda = 1$, households employ a simple random walk forecast. By comparison, the "sticky-information" model of Mankiw and Reis (2002) implies that the forecast at time t is based on an exponentially-weighted moving average of past rational forecasts. A sticky-information version of equation (20) could be written recursively as $F_t X_{t+1} = F_{t-1} X_t + \mu \left(E_t X_{t+1} - F_{t-1} X_t \right)$, where μ represents the fraction of households who update their forecast to the most-recent rational forecast $E_t X_{t+1}$.

For each of the model's first order conditions, we nest the moving-average forecast rule (20) together with the rational expectation $E_t X_{t+1}$ to obtain the following "hybrid expectation" which is a weighted-average of the two forecasts

$$
\widehat{E}_{j,t} X_{t+1} = \omega F_t X_{t+1} + (1-\omega)\, E_t X_{t+1}, \qquad 0 \leq \omega \leq 1, \qquad j = 1, 2, \qquad (21)
$$

where ω can be interpreted as the fraction of households who employ the moving-average forecast rule (20). For simplicity, we assume that ω is the same for both types of households. In equilibrium, the fully-rational forecast $E_t X_{t+1}$ takes into account the influence of households who employ the moving-average forecast rule. Although the parameters ω and λ influence the volatility and persistence of the model variables, they do not affect the deterministic steady state.

3 Model Calibration

Table 1 summarizes our choice of parameter values. Some parameters are set to achieve target values for steady-state variables while others are set to commonly-used values in the literature.[22] The time period in the model is one quarter. The number of impatient households relative to patient households is $n = 0.9$ so that patient households represent the top decile of households in the model economy. In the model, patient households own 100% of physical capital wealth. The top decile of U.S. households owns approximately 80% of financial wealth and about 70% of total wealth including real estate. Our setup implies a Gini coefficient for physical capital wealth of 0.90. The Gini coefficient for financial wealth in U.S. data has ranged between 0.89 and 0.93 over the period 1983 to 2001.[23] The labor disutility parameters $\nu_{1,L}$ and $\nu_{2,L}$, together with the capital share of income parameter α, are set so that the top income decile in the model earns 40% of total income (including firm profits) in steady state, consistent with the long-run average income share measured by Piketty and Saez (2003).[24] The elasticity parameter $\theta = 33.33$ is set to yield a steady-state price mark-up of about 3%.

The discount factor of patient households is set to $\beta_1 = 0.99$ such that the annualized steady-state real lending rate is 4%. The discount factor for impatient agents is set to $\beta_2 = 0.95$, thus generating a strong desire for borrowing. The investment adjustment cost parameter $\psi = 5$ is in line with values typically estimated in DSGE models. Capital depreciates at a typical quarterly rate of $\delta = 0.025$. The habit formation parameter is $b = 0.5$. The labor supply elasticity parameter is set to $\varphi_L = 0.1$, implying a very flexible labor supply. The housing weights in the utility functions are set to $\nu_{1,h} = 0.3$ and $\nu_{2,h} = 0.1$ for the patient and impatient households, respectively. Our calibration implies that the top income decile of households derive a relatively higher per unit utility from housing services. Together, these values imply a steady-state ratio of total housing wealth to annualized GDP of 1.98. According to Iacoviello (2010), the corresponding ratio in U.S. data has ranged between 1.2 and 2.3 over the period 1952 to 2008.

The Calvo parameter $\theta_\pi = 0.75$ and the indexation parameter $\iota_\pi = 0.5$ represent typical values in the literature. The interest rate responses to inflation and quarterly output are $\alpha_\pi = 1.5$ and $\alpha_y = 0.125$. The absence of interest rate smoothing justifies a positive value of $\rho_\varsigma = 0.4$ for the persistence of the monetary policy shock.

The calibration of the forecast rule parameters ω and λ requires a more detailed description. Our aim is to magnify the volatility of house prices and household debt while maintaining pro-cyclical movement in both variables. Figure 5 shows how different combinations of ω and λ affect the volatility and co-movement of selected model variables. When $\lambda \lesssim 0.18$, a unique stable equilibrium does not exist for that particular combination of ω and λ. The baseline calibration of $\omega = 0.30$ and $\lambda = 0.35$ delivers excess volatility and maintains pro-cyclical movement in house prices and household debt. Even though only 30% of households in the

[22] See, for example, Iacoviello and Neri (2010).
[23] See Wolff (2006), Table 4.2, p. 113.
[24] Updated data through 2010 are available from Emmanuel Saez's website: http://elsa.berkeley.edu/~saez/.

model employ a moving-average forecast rule, the presence of these agents influences the nature of the rational forecasts employed by the remaining 70% of households.[25]

For the generalized interest rate rule (18), we set $\alpha_q = 0.2$ or $\alpha_b = 0.2$ to illustrate the effects of a direct interest rate response to financial variables. Very high values for these parameters can sometimes lead to instability of the steady state. The constant loan-to-value ratio in the baseline model is $\gamma = 0.7$. This is consistent with the long-run average loan-to-value ratio of U.S. residential mortgage holders.[26] In the generalized borrowing constraint (19), we set $m = 0.5$ which requires the lender to place a substantial weight on the borrowers wage income. In this case, we set $\widehat{\gamma} = 1.072$ to maintain the same steady state loan-to-value ratio as in the baseline model with $m = 0$.

In the sensitivity analysis, we examine the volatility effects of varying the key policy parameters over a wide range of values. Specifically, we consider $\alpha_q,\ \alpha_b \in [0,\ 0.4]$, $\gamma \in [0.2,\ 1.0]$, and $m \in [0,\ 1.0]$.

4 Excess Volatility

In this section, we show that the hybrid expectations model generates excess volatility in asset prices and household debt while at the same time delivering co-movement between house prices, household debt, and real output. In this way, the model is better able to match the patterns observed in many developed countries over the past decade.

Figure 6 depicts simulated time series for the house price, household debt, the price of capital q_t^k (which we interpret as a stock price index), aggregate real consumption, real output, aggregate labor hours, inflation, and the policy interest rate R_t. All series are plotted as percent deviations from steady state values without applying any filter. The figure shows that the hybrid expectations model serves to magnify the volatility of most model variables. This is not surprising given that the moving-average forecast rule (20) embeds a unit root assumption. This is most obvious when $\lambda = 1$ but is also true when $0 < \lambda < 1$ because the weights on lagged variables sum to unity. Due to the self-referential nature of the equilibrium conditions, the households' subjective forecast influences the dynamics of the object that is being forecasted.[27]

[25] Levine et al. (2012) employ a specification for expectations that is very similar to our equations (20) and (21). However, their DSGE model omits house prices and household debt. They estimate the fraction of backward-looking agents (ω in our model) in the range of 0.65 to 0.83 with a moving-average forecast parameter (λ in our model) in the range of 0.1 to 0.4.

[26] We thank Bill Emmons of the Federal Reserve Bank of St. Louis for kindly providing this data, which are plotted in Figure 4.

[27] A simple example with $\lambda = 1$ illustrates the point. Suppose that the Phillips curve is given by $\pi_t = \beta\, \widehat{E}_t\, \pi_{t+1} + y_t$, where y_t follows an AR(1) process with persistence ρ and $\widehat{E}_t \pi_{t+1} = \omega F_t \pi_{t+1} + (1-\omega)\, E_t \pi_{t+1}$. When $F_t \pi_{t+1} = \pi_t$, the equilibrium law of motion is $\pi_t = y_t / \left[1 - \beta\omega - \rho\beta\,(1-\omega)\right]$, which implies $Var\,(\pi_t) = Var\,(y_t) / \left[1 - \beta\omega - \rho\beta\,(1-\omega)\right]^2$ .When $\rho < 1$, both $Var\,(\pi_t)$ and $Var\,(E_t \pi_{t+1})$ are increasing in the fraction of agents ω who employ a random walk forecast.

The use of moving-average forecast rules by a subset of agents also influences the nature of the fully-rational forecast rules employed by the remaining agents. Both of these channels serve to magnify volatility.

Table 2 compares volatilities under rational expectations ($\omega = 0$) to those under hybrid expectations where a fraction $\omega = 0.30$ of agents employ moving-average forecast rules. Excess volatility is greatest for the household debt series which is magnified by a factor 2.07. The volatility of house prices is magnified by a factor of 1.77. House price volatility is magnified by less than debt volatility because the patient-lender households in the model do not use debt for the purchase of housing services. The volatility of labor hours is magnified by a factor of 1.92 whereas output volatility is magnified by a factor of 1.36. Stock price volatility is magnified by a factor of 1.30. The volatilities of the other variables are also magnified, but in a less dramatic way. Consumption volatility is magnified by a factor 1.12.

Given the calibration of the shocks, the hybrid expectations model approximately matches the standard deviations of log-linearly detrended U.S. real house prices, real household debt per capita, and real GDP per capita over the period 1965 to 2009. A comparison of the model simulations shown in Figure 6 with the U.S. data shown earlier in Figure 1 confirms that the model fluctuations for these variables are similar in amplitude to those in the detrended data. Another salient feature of the recent U.S. data, reproduced by the hybrid expectations model, is the co-movement of GDP, house prices, and household debt. Our simulations mimic the evidence that in a period of economic expansion, a house price boom is accompanied by an increase in household debt, as the collateral constraint allows both to move up simultaneously.

Table 3 shows that the persistence of most model variables is higher under hybrid expectations. The autocorrelation coefficient for house prices goes from 0.90 under rational expectations to 0.97 under hybrid expectations, whereas the autocorrelation coefficient for household debt goes from 0.79 to 0.94. The increased persistence improves the model's ability to produce large swings in house prices and household debt, as was observed in many developed countries over the past decade.

Figures 7 through 9 plot impulse response functions. In the case of all three shocks, the resulting fluctuations in the hybrid expectations model tend to be more pronounced and longer lasting. The overreaction of house prices and stock prices to fundamental shocks in the hybrid expectations model is consistent with historical interpretations of bubbles. As noted by Greenspan (2002), "Bubbles are often precipitated by perceptions of real improvements in the productivity and underlying profitability of the corporate economy. But as history attests, investors then too often exaggerate the extent of the improvement in economic fundamentals."

As noted in the introduction, countries with the largest increases in household leverage tended to experience the fastest run-ups in house prices from 1997 to 2007. The same countries tended to experience the most severe declines in consumption once house prices started falling.

The hybrid expectations model delivers the result that excess volatility in house prices and household debt also gives rise to excess volatility in consumption. Hence, central bank efforts to dampen boom-bust cycles in housing and credit may yield significant welfare benefits from smoother consumption.

Central bank loss functions are often modeled as a weighted-sum of squared deviations of inflation and output from targets. In our model, such a loss function is equivalent to a weighted-sum of the unconditional variances of inflation and output since the target (or steady-state) values of both variables equal zero. The results shown in Table 2 imply a higher loss function realization under hybrid expectations. As discussed further in the next section, a concern for financial stability might be reflected in an expanded loss function that takes into account the variance of household debt. In this case, the high volatility of household debt observed under hybrid expectations would imply a higher loss function realization and hence a stronger motive for central bank stabilization policy.

5 Policy Experiments

In this section, we evaluate various policy actions that might be used to dampen excess volatility in the model economy. We first examine the merits of a direct response to either house price growth or household debt growth in the central bank's interest rate rule. Next, we analyze the use of two macroprudential policy tools that affect the borrowing constraint, i.e., a permanent reduction in the loan-to-value ratio and a policy that directs lenders to place increased emphasis on the borrower's wage income in determining how much they can borrow.

5.1 Interest Rate Response to House Price Growth or Credit Growth

The generalized interest rate rule (18) allows for a direct response to either house price growth credit growth. As an illustrative case, Table 3 shows the results when the central bank responds to the selected financial variable with a coefficient of $\alpha_q = 0.2$ or $\alpha_b = 0.2$.

The top panel of Table 4 shows that under rational expectations, responding to house prices does not yield any stabilization benefits for output but the volatility of labor hours is magnified by a factor of 1.29 (relative to the no-response version of the same model). The standard deviation of inflation is somewhat magnified with a volatility ratio of 1.06. These results are in line with Iacoviello (2005) who finds little or no stabilization benefits for an interest rate response to the level of house prices in a rational expectations model. The largest stabilization effect under rational expectations is achieved with household debt which exhibits a volatility ratio 0.77. Consumption volatility is reduced with a ratio 0.95. Under hybrid expectations, responding to house price growth yields qualitatively similar results. However, the undesirable magnification of inflation volatility is now *quantitatively* much larger—exhibiting a volatility ratio of 1.21. The policy under hybrid expectations delivers some stabilization benefits for household debt (volatility ratio of 0.93), but consumption volatility is little changed (volatility ratio of 0.99) and labor hours volatility is magnified (volatility ratio of 1.15).

The bottom panel of Table 4 shows the results for an interest rate response to credit growth. Under rational expectations, the results are broadly similar to an interest rate response to house price growth. However, under hybrid expectations, responding to credit growth now performs poorly. Specifically, inflation volatility is magnified by a factor of 1.83 and there is no compensating reduction in the volatility of household debt. On the contrary, debt volatility is slightly magnified by a factor of 1.03. The volatility of labor hours is magnified by a factor of 1.06. These results demonstrate that the stabilization benefits of a particular monetary policy can be influenced by the nature of agents' expectations. Under rational expectations, the impatient households understand that an increase in borrowing will contribute to higher interest rates which in turn, will raise the cost of borrowing. This expectations channel serves to dampen fluctuations in household debt. But under hybrid expectations, this channel becomes less effective because a subset of borrowers construct forecasts using a moving-average of past values.

Figures 10 and 11 plot the results for hybrid expectations when we allow α_q or α_b to vary from a low 0 to a high of 0.4. Both policy rules end up magnifying the volatility of output, labor hours, and inflation, with the undesirable effect on inflation being more severe when responding to credit growth. In the lower right panel of the figure, we plot the realized values of two illustrative loss functions that are intended to represent plausible stabilization goals of a central bank. Loss function 1 is a commonly-used specification consisting of an equal-weighted sum of the unconditional variances of inflation and output. Loss function 2 includes an additional term not present in loss function 1, namely, the unconditional variance of household debt which is assigned a relative weight of 0.25. We interpret the additional term as reflecting the central bank's concern for financial stability. Here, we link the concern for financial stability to a variable that measures household leverage whereas Woodford (2011) links this concern to a variable that measures financial sector leverage.

Figures 10 and 11 show that responding to either house price growth or credit growth is detrimental from the standpoint of loss function 1. However, in light of the severe economic fallout from the recent financial crisis, views regarding the central bank's role in ensuring financial stability appear to be shifting. From the standpoint of loss function 2, an interest rate response to house price growth achieves some success in reducing the loss, provided that the response coefficient α_q is not too large. In contrast, an interest rate response to credit growth remains detrimental under loss function 2 because the policy does not stabilize fluctuations in household debt.

As a caveat to the above results, we acknowledge that the parameters of the Taylor-type interest rate rule (18) have not been optimized to minimize the value of any loss function. Moreover, unlike an optimal simple rule, the fully-optimal monetary policy should respond to all state variables in the model. In the case of hybrid expectations, the lagged expectation of backward-looking agents (i.e., the lagged moving average of the forecast variable) would represent an additional state variable that should appear in the central bank's fully-optimal policy rule. While an exploration of optimal monetary policy is beyond the scope of this paper, such an exploration might identify some stabilization benefits to responding to either house price growth or credit growth.

5.2 Tightening of Lending Standards: Decrease LTV

The top panel of Table 5 shows the results for a macroprudential policy that permanently tightens lending standards by reducing the maximum loan-to-value ratio γ in equation (3) from 0.7 to 0.5. Under both rational and hybrid expectations, the policy succeeds in reducing the volatility of household debt, but the volatility of most other variables, including output, labor hours, and inflation are slightly magnified.

Figure 12 plots the results for hybrid expectations when we allow γ to vary from a low 0.2 to a high of 1.0. The figure shows that *higher* values of γ (implying looser lending standards) reduce the volatility of output, labor hours, inflation, and consumption over a middle range of loan-to-value ratios. However, as γ approaches 1.0, the volatilities of inflation and consumption start increasing again.

The volatility patterns shown in Figure 12 illustrate a complicated policy trade-off. On the one hand, a tightening of lending standards can stabilize household debt and thereby help promote financial stability. But on the other hand, permanently restricting access to borrowed money will impair the ability of impatient households to smooth their consumption, thus magnifying the volatility of aggregate consumption, as well as output, aggregate labor hours, and inflation.

In the lower right panel of Figure 12, we see that a decrease in γ starting from 0.7 is detrimental from the standpoint of loss function 1 which only considers output and inflation. However, the same policy is beneficial from the standpoint of loss function 2 which takes into account financial stability via fluctuations in household debt. Under these circumstances, a decision by regulators to tighten lending standards could be met with opposition from those who do not share the regulator's concern for financial stability.

5.3 Wage Income in the Borrowing Constraint

The bottom panel of Table 5 shows the results for a macroprudential policy that requires lenders to place a substantial emphasis on the borrower's wage income in the borrowing constraint. Specifically, we set $m = 0.5$ in equation (19) with $\widehat{\gamma} = 1.072$ so as to leave the steady-state loan-to-value ratio unchanged from the baseline model with $m = 0$.

Under both expectations regimes, the policy succeeds in reducing the volatility of household debt. Under rational expectations, the volatility of household debt is reduced by a factor of 0.86. Under hybrid expectations, debt volatility is reduced by a factor 0.68. The volatility effects on the other variables are generally quite small, but for the most part, volatilities are reduced under hybrid expectations.

Figure 13 plots the results for hybrid expectations when we allow m to vary from a low of zero (representing a pure loan-to-value constraint) to a high of 1.0 (representing a pure loan-to-income constraint). As m increases, the policy achieves small reductions in the volatilities of output, labor hours, inflation, and consumption. Notably, the policy avoids the undesirable magnification of inflation volatility that was observed in the two interest rate policy experiments. In this sense, the present policy can be viewed as superior simply because it avoids doing harm. In the lower right panel of the figure, we see that an increase in m achieves small stabilization benefits from the standpoint of loss function 1, but much larger benefits from the standpoint of loss function 2.

Figure 14 shows that the generalized borrowing constraint with $m = 0.5$ induces endogenous countercyclicality of the loan-to-value ratio. In this way, the policy serves as an "automatic stabilizer" for household debt. The intuition for this result is straightforward. Dividing both side of equation (19) by $\left[\widehat{E}_{1,t}\, q_{t+1}\pi_{t+1}\right]\, h_{2t}/R_t$ we obtain

$$\frac{b_{2t}\ R_t}{\left[\widehat{E}_{1,t}\, q_{t+1}\pi_{t+1}\right]\ h_{2t}} \ \leq\ \widehat{\gamma}\left\{\frac{m\, w_t L_{2t}}{\left[\widehat{E}_{1,t}\, q_{t+1}\pi_{t+1}\right]\ h_{2t}} + 1 - m\right\}, \tag{22}$$

where the left-side variable is the equilibrium loan-to-value ratio plotted in Figure 14. When $m = 0$, the left-side variable is constant. However when $m > 0$, the left-side variable will move down if the lender's expected collateral value $\left[\widehat{E}_{1,t}\, q_{t+1}\pi_{t+1}\right]\ h_{2t}$ is increasing faster than the borrower's wage income $w_t L_{2,t}$. The figure shows that the endogenous countercyclicality is stronger under hybrid expectations.

Housing values in the U.S. rose faster than wage income during the boom years of the mid-2000s. Unfortunately, lenders did not react by tightening lending standards as called for by a constraint such as (22). On the contrary, lending standards deteriorated as the boom progressed. Rather than placing a substantial weight on the borrower's wage income in the underwriting decision, lenders increasingly approved mortgages with little or no documentation of income.[28] As mentioned in the introduction, a number of recent papers have explored

[28] According to the U.S. Financial Crisis Inquiry Commission (2011), p. 165, "Overall, by 2006, no-doc or low-doc loans made up 27% of all mortgages originated."

the stabilization benefits of countercyclical loan-to-value rules in rational expectations models. While it may be possible to successfully implement such state-contingent rules within a regulatory framework, it seems much easier and more transparent for regulators to simply mandate a substantial emphasis on the borrower's wage income in the lending decision.

6 Conclusion

There are many examples in history of asset prices exhibiting sustained run-ups that are difficult to justify on the basis of economic fundamentals. The typical transitory nature of these run-ups should perhaps be viewed as a long-run victory for fundamental asset pricing theory. Still, it remains a challenge for fundamental theory to explain the ever-present volatility of asset prices within a framework of efficient markets and fully-rational agents.

This paper showed that the introduction of a subset of agents who employ simple moving-average forecast rules can significantly magnify the volatility of house prices and household debt versus an otherwise similar model with fully-rational agents. A wide variety of empirical evidence supports the idea that expectations are often less than fully-rational. One obvious example can be found in survey-based measures of U.S. inflation expectations which are well-captured by a moving average of past inflation rates. A moving-average forecast rule can also be justified as an approximation to a standard Kalman filter algorithm in which the forecast variable is subject to both permanent and temporary shocks.

The extensive harm caused by the global financial crisis raises the question of whether policymakers could have done more to prevent the buildup of dangerous financial imbalances, particularly in the household sector. The U.S. Financial Crisis Inquiry Commission (2011) concluded, "Despite the expressed view of many on Wall Street and in Washington that the crisis could not have been foreseen or avoided, there were warning signs. The tragedy was that they were ignored or discounted. There was an explosion in risky subprime lending and securitization, an unsustainable rise in housing prices, widespread reports of egregious and predatory lending practices, dramatic increases in household mortgage debt... among many other red flags. Yet there was pervasive permissiveness; little meaningful action was taken to quell the threats in a timely manner." In the aftermath of the crisis, there remain important unresolved questions about whether regulators should attempt to lean against suspected bubbles and if so, what policy instruments should be used to do so.

This paper evaluated the performance of some monetary and macroprudential policy tools as a way of dampening excess volatility in a DSGE model with housing. While no policy tool was perfect, some performed better than others. A direct response to either house price growth or credit growth in the central bank's interest rate rule had the serious drawback of substantially magnifying the volatility of inflation. A tightening of lending standards, in the form of a lower LTV ratio, mildly raised the volatilities of output, labor hours, inflation, and consumption, but was successful in reducing the volatility of household debt—a benefit from a financial stability perspective. The best-performing policy was one that required lenders to place a substantial weight on the borrower's wage income in the borrowing constraint. This policy contributed to both economic and financial stability; it mildly reduced the volatilities of output, labor hours, inflation, and consumption while at the same time it substantially reduced fluctuations in household debt.

Interestingly, the most successful stabilization policy in our model calls for lending behavior that is basically the opposite of what was observed during U.S. housing boom of the mid-2000s. As the boom progressed, U.S. lenders placed less emphasis on the borrower's wage income and more emphasis on expected future house prices. So-called "no-doc" and "low-doc" loans became increasingly popular. Loans were approved that could only perform if house prices continued to rise, thereby allowing borrowers to refinance. It retrospect, it seems likely that stricter adherence to prudent loan-to-income guidelines would have forestalled much of the housing boom, such that the subsequent reversal and the resulting financial turmoil would have been less severe.

References

Adam, K., P. Kuang, and A. Marcet 2012 House price booms and the current account, NBER Macroeconomics Annual 2011, forthcoming.

Airaudo, M., R. Cardani, and K.J. Lansing 2012 Monetary policy and asset prices with belief-driven fluctuations, Working Paper.

Akram, Q. F. and Ø. Eitrheim 2008 Flexible inflation targeting and financial stability: Is it enough to stabilize inflation and output? Journal of Banking and Finance 32, 1242–1254.

Angelini, P., S. Neri, and F. Panetta 2010 Macroeconomic stabilization policies: Grafting macroprudential tools in a macroeconomic framework, Bank of Italy, Working Paper.

Bank of England 2011 Instruments of macroprudential policy, Discussion Paper (December).

Bernanke, B.S. and M. Gertler 2001 Should central banks respond to movements in asset prices? American Economic Review, Papers and Proceedings 91, 253-257.

Boivin, J., T. Lane, and C. Meh 2010 Should monetary policy be used to counteract financial imbalances? Bank of Canada, Review, Summer, pp 23-36.

Borio, C. and P. Lowe 2002 Asset prices, financial and monetary stability: Exploring the nexus, Bank for International Settlements Working Paper 114.

Calvo, G.A. 1983 Staggered prices in a utility maximizing framework,Journal of Monetary Economics 12, 383-398.

Campbell, S., M.A. Davis, J. Gallin, and R.F. Martin 2009 What moves housing markets: A variance decomposition of the price-rent ratio, Journal of Urban Economics 66, 90-102.

Carroll, C. 2003. Macroeconomic expectations of households and professional forecasters, Quarterly Journal of Economics 118, 269-298.

Cecchetti, S.G., H. Genberg, and S. Wadhwani 2002. Asset prices in a flexible inflation targeting framework, in W. C. Hunter, G. G. Kaufman and M. Pomerleano, eds., Asset Price Bubbles: Implications for Monetary, Regulatory, and International Policies. Cambridge, MA: MIT Press.

Christensen, I. and C.A. Meh 2011 Countercyclical loan-to-value ratios and monetary policy, Bank of Canada, Working Paper.

Christiano, L., C. Ilut, R. Motto, and M. Rostagno 2010 Monetary policy and stock market booms, in Federal Reserve Bank of Kansas City Economic Policy Symposium, Macroeconomic Challenges: The Decade Ahead.

Chow, G.C. 1989 Rational versus adaptive expectations in present value models, Review of Economics and Statistics 71, 385-393.

Coibion, O. and Y. Gorodnichencko 2012 What can survey forecasts tell us about informational rigidities? Journal of Political Economy, forthcoming.

Committee on International Economic and Policy Reform 2011 Rethinking central banking, Brookings Institution Report (September).

Davis, M.A., A. Lehnert, and R.F. Martin 2008, The rent-price ratio for the aggregate stock of owner-occupied housing, Review of Income and Wealth 54, 279-284.

De Grauwe, P. 2012 Booms and busts: New Keynesian and behavioral explanations, Journal of Economic Behavior and Organization, forthcoming.

Drehmann, M., C. Borio, and K. Tsatsaronis 2012 Characterizing the financial cycle: Don't lose sight of the medium term, Bank for International Settlements Working Paper 380.

Dupor, B. 2005 Stabilizing non-fundamental asset price movements under discretion and limited information, Journal of Monetary Economics 52, 727-747.

Eusepi, S. and B. Preston 2011 Expectations, learning, and business cycle fluctuations, American Economic Review 101, 2844-2872.

Evans, G.W. and S. Honkapohja 2001 Learning and expectations in economics. Princeton: Princeton University Press.

Evans, G.W. and G. Ramey 2006 Adaptive expectations, underparameterization, and the Lucas critique, Journal of Monetary Economics 53, 249-264.

Fischer, I. 1933 The debt-deflation theory of great depressions, Econometrica 1, 337-357.

Filardo, A. 2008 Household debt, monetary policy, and financial stability: Still searching for a unifying model, Bank for International Settlements, Research Paper.

Galati, G. and R. Moessner 2011 Macroprudential policy, A literature review, Bank for International Settlements, Working Paper 337.

Gilchrist, S. and J.V. Leahy 2002 Monetary policy and asset prices, Journal of Monetary Economics 49, 75-97.

Gilchrist, S. and M. Saito 2008 Expectations, asset prices, and monetary policy: The role of learning, in J.Y Campbell, ed., Asset Prices and Monetary Policy. Chicago: University of Chicago Press, pp. 45-102.

Gertler, M. N. Kiyotaki, and A. Queralto 2012 Financial crisis, bank risk exposure, and government financial policy, Journal of Monetary Economics, forthcoming.

Glick, R. and K.J. Lansing 2010 Global household leverage, house prices and consumption, Federal Reserve Bank of San Francisco Economic Letter 2010-01 (January 11).

Goetzmann, W.N., L. Peng and J. Yen 2012 The subprime crisis and house price appreciation, Journal of Real Estate Finance and Economics 44, 36-56.

Granziera, E. and S. Kozicki 2012 House price dynamics: Fundamentals and expectations, Bank of Canada, Working Paper 2012-12.

Greenspan, A., 2002 Economic volatility. Remarks at a symposium sponsored by the Federal Reserve Bank of Kansas City, Jackson Hole, Wyoming, August 30.

Greenspan, A., 2004 Understanding household debt obligations. Remarks at the Credit Union National Association 2004 Governmental Affairs Conference, Washington, D.C., February 23.

Huang, K., Z. Liu, and T. Zha 2009 Learning, adaptive expectations, and technology shocks, Economic Journal 119, 377-405.

Iacoviello, M. 2005 House prices, borrowing constraints, and monetary policy in the business cycle, American Economic Review, 95, 739-764.

Iacoviello, M. 2010 Housing in DSGE models: Findings and new directions, in O. de Bandt, T. Knetsch, J. Peñalosa, and F. Zollino, (eds.), Housing Markets in Europe: A Macroeconomic Perspective. Berlin, Hidelberg: Springer-Verlag, pp. 3-16.

Iacoviello, M. and S. Neri 2010 Housing market spillovers: Evidence from an estimated DSGE model, American Economic Journal: Macroeconomics 2, 125-164.

International Monetary Fund 2009 Lessons for monetary policy from asset price fluctuations, Chapter 3 of World Economic Outlook (WEO), Crisis and Recovery, (October).

International Monetary Fund 2012 Dealing with household debt, Chapter 3 of World Economic Outlook (WEO), Growth Resuming, Dangers Remain, (April).

Jurgilas, M. and K.J. Lansing 2012 Housing bubbles and homeownership returns, Federal Reserve Bank of San Francisco Economic Letter 2012-19 (June 25).

Kannan, P., P. Rabanal, and A. Scott 2009 Monetary and macroprudential policy rules in a model with house price booms, IMF Working Paper 09/251.

King, M. 1994 Debt deflation: Theory and evidence, European Economic Review 38, 419-445.

Kocherlakota. N. 2009 Modern macroeconomic models as tools for economic policy, Federal reserve Bank of Minneapolis, The Region, pp. 5-21.

Lambertini, L., C. Mendicino, and M.T. Punzi 2011 Leaning against boom-bust cycles in credit and housing prices, Working Paper.

Lansing, K.J. 2008 Monetary policy and asset prices, Federal Reserve Bank of San Francisco Economic Letter 2008-34 (October 31).

Lansing, K.J. 2009 Time-varying U.S. inflation dynamics and the New Keynesian Phillips curve, Review of Economic Dynamics 12, 304-326.

Lansing, K.J. 2011 Gauging the impact of the great recession, Federal Reserve Bank of San Francisco Economic Letter 2011-21 (July 11).

Lansing, K.J. and LeRoy, S.F., 2012. Risk aversion, investor information, and stock market volatility. Federal Reserve Bank of San Francisco, Working Paper 2010-24.

LeRoy, S.F. and Porter, R.D., 1981. The present-value relation: Tests based on implied variance bounds. Econometrica 49, 555-577.

Lettau, M. and T. Van Zandt 2003 Robustness of adaptive expectations as an equilibrium selection device, Macroeconomic Dynamics 7, 89-118.

Levine, P., J. Pearlman, G. Perendia and B.Yang 2012 Endogenous persistence in an estimated DSGE model under imperfect information, Economic Journal, forthcoming.

Mankiw, N.G. and R. Reis 2002 Sticky information versus sticky prices: A proposal to replace the New Keynesian Phillips curve, Quarterly Journal of Economics 117, 1295-1328.

Mankiw, N.G., R. Reis, and J. Wolfers 2004 Disagreement about inflation expectations, in M. Gertler and K. Rogoff, eds., NBER Macroeconomics Annual 2003. Cambridge MA: MIT Press, pp. 209-248.

Mehra. Y.P. 2002 Survey measures of expected inflation: Revisiting the issues of predictive content and rationality, Federal Reserve Bank of Richmond Economic Quarterly 88/3, 17-36.

Mian, A. and A. Sufi 2009 The consequences of mortgage credit expansion: Evidence from the U.S. mortgage default crisis, Quarterly Journal of Economics 124, 1449-1496.

Mian, A. and A. Sufi 2010 Household leverage and the recession of 2007 to 2009, IMF Economic Review 58, 74-117.

Mian, A. and A. Sufi 2012 What explains high unemployment? The aggregate demand channel, NBER Working Paper 17830.

Milani, F. 2007 Expectations, learning and macroeconomic persistence, Journal of Monetary Economics 54, 2065-2082.

Muth, J.F. 1960 Optimal properties of exponentially weighted forecasts, Journal of the American Statistical Association 55, 299-306.

Nerlove, M. 1983 Expectations, plans, and realizations in theory and practice, Econometrica 51, 1251-1279.

Orphanides, A. and J.C. Williams 2005 Imperfect knowledge, inflation expectations, and monetary policy, in B. Bernanke and M. Woodford (eds.), The Inflation Targeting Debate. Chicago: University of Chicago Press, pp. 201-234.

Orphanides, A. and J.C. Williams 2009 Imperfect knowledge and the pitfalls of optimal control monetary policy, in K. Schmidt-Hebbel and C. Walsh (eds.), Central Banking, Analysis and Economic Policies: Monetary Policy Under Uncertainty and Learning 13, Central Bank of Chile, pp. 115-144.

Pavlov, A. and S.Wachter 2011 Subprime lending and real estate prices, Real Estate Economics 39, pp. 1-17.

Piketty, T. and E. Saez 2003 Income inequality in the United States, 1913-1998, Quarterly Journal of Economics 118, 1-39.

Reinhart, C.M. and V.R. Reinhart 2010 After the fall, Federal Reserve Bank of Kansas City Economic Policy Symposium, Macroeconomic Challenges: The Decade Ahead.

Roberts, J. 1997 Is inflation sticky? Journal of Monetary Economics 39, 173-196.

Roxburgh, C., S. Lund, T. Daruvala, J. Manyika, R. Dobbs, R. Forn, and K. Croxson 2012 Debt and deleveraging: Uneven progress on the path to growth, McKinsey Global Institute.

Sargent, T.J. 1996 Expectations and the nonneutrality of Lucas, Journal of Monetary Economics 37, 535–548.

Sargent, T.J. 1999 The Conquest of American Inflation. Princeton: Princeton University Press.

Shiller, R.J., 1981. Do stock prices move too much to be justified by subsequent changes in dividends? American Economic Review 71, 421-436.

U.S. Financial Crisis Inquiry Commission 2011 Final Report on the Causes of the Financial and Economic Crisis in the United States, Pursuant to Public Law 111-2 (January).

Walentin, K. and P. Sellin 2010 Housing collateral and the monetary transmission mechanism, Sverges Riksbank Working Paper 239.

Wolff, E.N. 2006 Changes in household wealth in the 1980s and 1990s in the U.S., in E.N. Wolff (ed.), International Perspectives on Household Wealth. Northampton MA: Edward Elgar Publishing Inc., pp. 107-150.

Woodford, M. 2011 Inflation targeting and financial stability, Columbia University, Working Paper.

Table 1: Model Calibration

Parameter	**Symbol**	**Value**
Capital's share of total income	α	0.342
Capital depreciation rate	δ	0.025
Investment adjustment cost	ψ	5
Discount factor of patient households	β_1	0.99
Discount factor of impatient households	β_2	0.95
Habit formation parameter	b	0.5
Labor supply elasticity parameter	φ_L	0.1
Disutility of labor, patient households	$\nu_{1,L}$	1.00
Disutility of labor, impatient households	$\nu_{2,L}$	2.93
Utility from housing services, patient households	$\nu_{1,h}$	0.30
Utility from housing services, impatient households	$\nu_{2,h}$	0.10
Steady state loan-to-value ratio	γ	0.7
Calvo price adjustment parameter	θ_π	0.75
Price indexation parameter	ι_π	0.50
Elasticity of substitution for intermediate goods	θ	33.33
Technology shock standard deviation	σ_z	0.01
Cost-push shock standard deviation	σ_u	0.005
Monetary policy shock standard deviation	σ_ς	0.003
Technology shock persistence	ρ_z	0.9
Cost-push shock persistence	ρ_u	0
Monetary policy shock persistence	ρ_ς	0.4
Interest rate response to inflation	α_π	1.5
Interest rate response to output	α_y	0.125
Interest rate response to credit growth	α_b	0 or 0.2
Interest rate response to house price growth	α_q	0 or 0.2
Fraction of agents with moving-average forecast rule	ω	0.30
Weight on recent data in moving-average forecast rule	λ	0.35
Weight on wage income in borrowing constraint	m	0 or 0.5
Level parameter in generalized borrowing constraint	$\widehat{\gamma}$	1.072

Table 2. Volatility Comparison: Rational versus Hybrid Expectations

	Standard deviations							
	House Price	Household Debt	Price of Capital	Consum.	Output	Labor Hours	Infl.	Policy Rate
Rational Expectations	2.05	3.17	1.04	1.87	2.31	1.12	0.81	0.99
Hybrid Expectations	3.62	6.55	1.35	2.09	3.14	2.15	0.90	1.07
Volatility Ratio	1.77	2.07	1.30	1.12	1.36	1.92	1.11	1.08

Standard deviations are computed using simulated series and expressed as percent deviation from steady state.

Table 3. Persistence Comparison: Rational versus Hybrid Expectations

	Autocorrelation coefficient							
	House price	Household Debt	Price of Capital	Consum.	Output	Labor Hours	Infl.	Policy rate
Rational Expectations	0.90	0.79	0.73	0.55	0.98	0.77	0.93	0.97
Hybrid Expectations	0.97	0.94	0.81	0.80	0.99	0.77	0.94	0.99
Persistence Ratio	1.07	1.19	1.11	1.60	1.01	1.00	1.01	1.02

Autocorrelation coefficients are computed using simulated series.

Table 4. Monetary Policy Experiments

	Standard deviations							
	House Price	Household Debt	Price of Capital	Consum.	Output	Labor Hours	Infl.	Policy Rate
	Interest rate response to house price growth ($\alpha_q = 0.2$)							
Rational								
Not responding	2.08	3.17	1.04	1.87	2.31	1.12	0.81	0.99
Responding	2.14	2.45	0.97	1.77	2.32	1.44	0.86	0.92
Volatility Ratio	1.03	0.77	0.93	0.95	1.00	1.29	1.06	0.93
Hybrid								
Not responding	3.62	6.55	1.35	2.09	3.14	2.15	0.90	1.07
Responding	3.82	6.06	1.44	2.06	3.23	2.47	1.09	1.21
Volatility Ratio	1.06	0.93	1.07	0.99	1.03	1.15	1.21	1.13
	Interest rate response to credit growth ($\alpha_b = 0.2$)							
Rational								
Not responding	2.08	3.17	1.04	1.87	2.31	1.12	0.81	0.99
Responding	2.14	2.00	1.01	1.83	2.34	1.25	0.84	0.94
Volatility Ratio	1.03	0.63	0.97	0.97	1.01	1.12	1.04	0.95
Hybrid								
Not responding	3.62	6.55	1.35	2.09	3.14	2.15	0.90	1.07
Responding	3.72	6.68	1.39	2.11	3.18	2.28	1.65	1.64
Volatility Ratio	1.03	1.02	1.03	1.01	1.01	1.06	1.83	1.53

Standard deviations are computed using simulated series and expressed as percent deviations from steady state.

Table 5. Macroprudential Policy Experiments

	Standard deviations							
	House Price	Household Debt	Price of Capital	Consum.	Output	Labor Hours	Infl.	Policy Rate
	Reduced loan-to-value ratio							
Rational								
$\gamma = 0.7$	2.08	3.17	1.04	1.87	2.31	1.12	0.81	0.99
$\gamma = 0.5$	2.21	2.46	1.12	1.86	2.35	0.99	0.84	1.05
Volatility Ratio	1.06	0.78	1.08	0.99	1.02	0.99	1.04	1.06
Hybrid								
$\gamma = 0.7$	3.62	6.55	1.35	2.09	3.14	2.15	0.90	1.07
$\gamma = 0.5$	3.73	5.34	1.41	2.11	3.21	2.16	0.91	1.10
Volatility Ratio	1.03	0.82	1.04	1.01	1.02	1.00	1.01	1.03
	Generalized borrowing constraint							
Rational								
$m = 0$	2.08	3.17	1.04	1.87	2.31	1.12	0.81	0.99
$m = 0.5$	2.12	2.68	1.06	1.86	2.32	1.14	0.81	1.01
Volatility Ratio	1.02	0.86	1.01	0.99	1.00	1.02	1.00	1.02
Hybrid								
$m = 0$	3.62	6.55	1.35	2.09	3.14	2.15	0.90	1.07
$m = 0.5$	3.63	4.43	1.34	2.08	3.12	2.05	0.89	1.08
Volatility Ratio	1.00	0.68	0.99	1.00	0.99	0.95	0.99	1.01

Standard deviations are computed using simulated series and expressed as percent deviations from steady state.

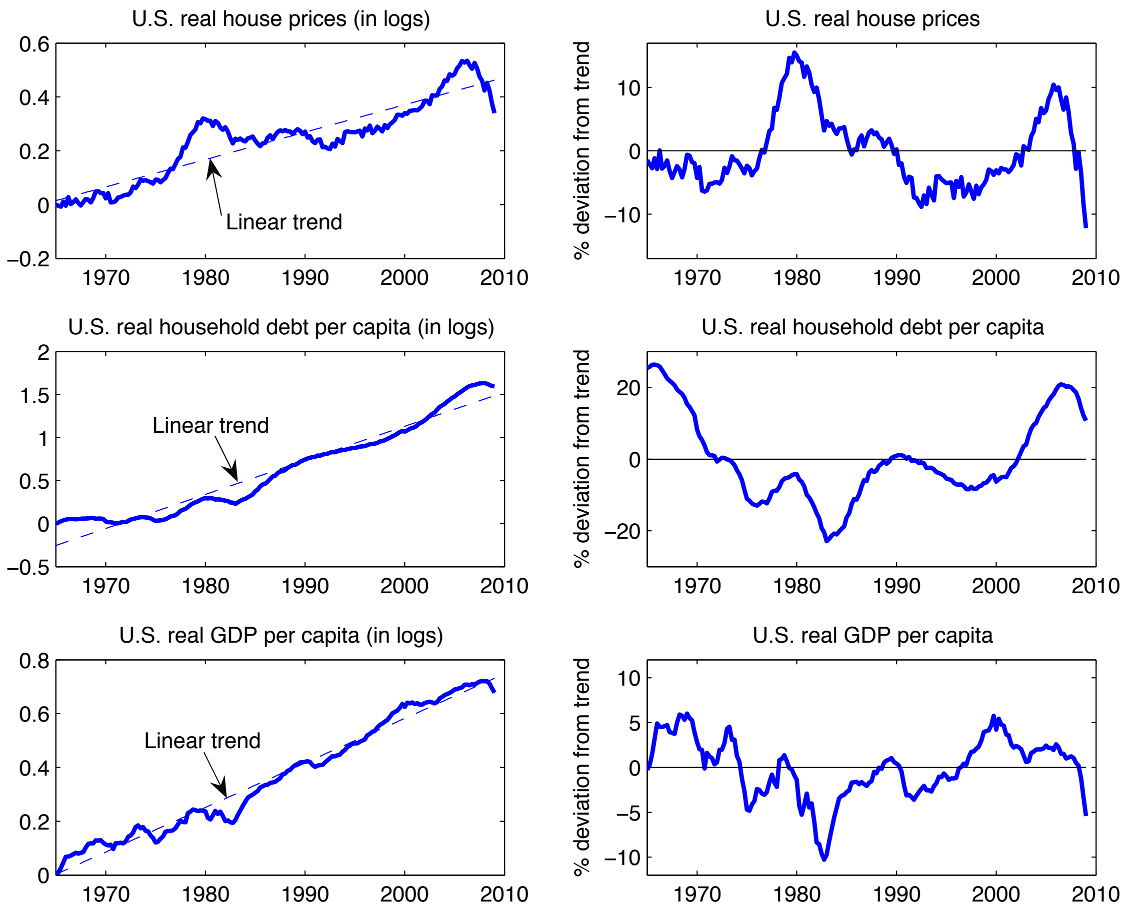

Figure 1: U.S. real house prices (from U.S. Census Bureau) and real household debt (from U.S. Flow of Funds) both increased dramatically starting around the year 2000. During the boom years, per capita real GDP remained consistently above trend. House prices have since retraced to the downside while the level of household debt has declined slightly. Real GDP experienced a sharp drop during the Great Recession and remains about 5% below trend.

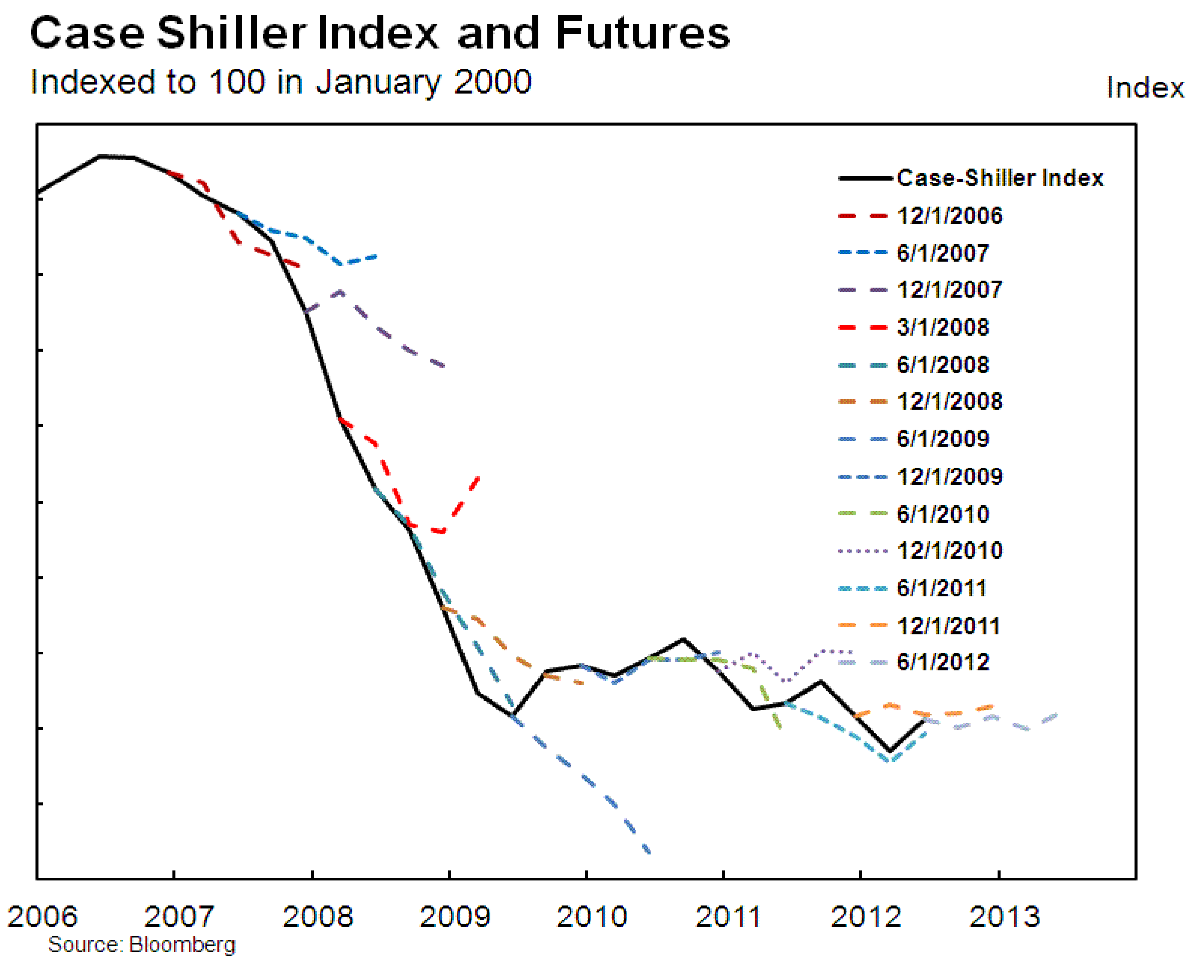

Figure 2: Futures market forecasts for house prices tend to overpredict subsequent actual house prices when prices are falling—a pattern consistent with a moving-average forecast rule.

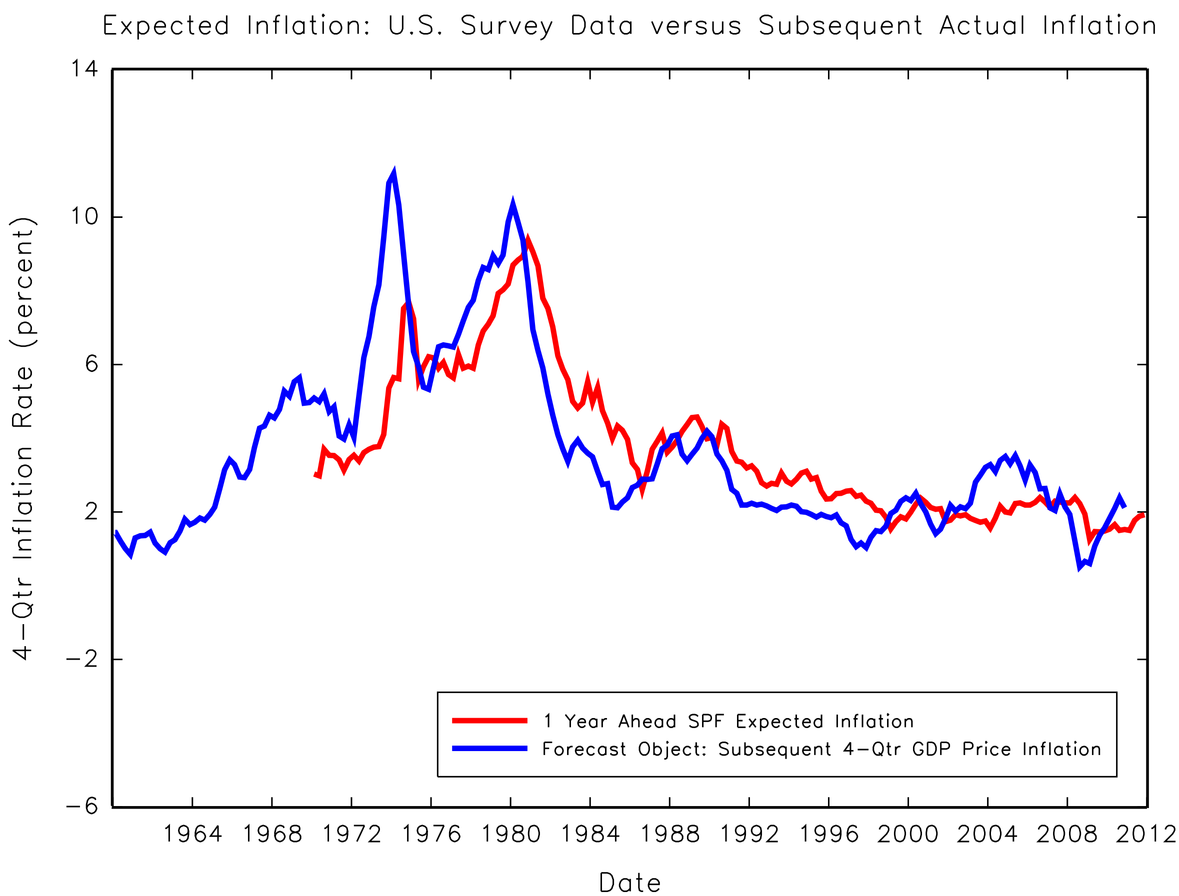

Figure 3: U.S. inflation expectations derived from the Survey of Professional Forecasters (SPF) tend to systematically underpredict subsequent actual inflation in the sample period prior to 1979 when inflation was rising and systematically overpredict it thereafter when inflation was falling. The survey pattern is well-captured by moving-average of past inflation rates, as shown by Lansing (2009).

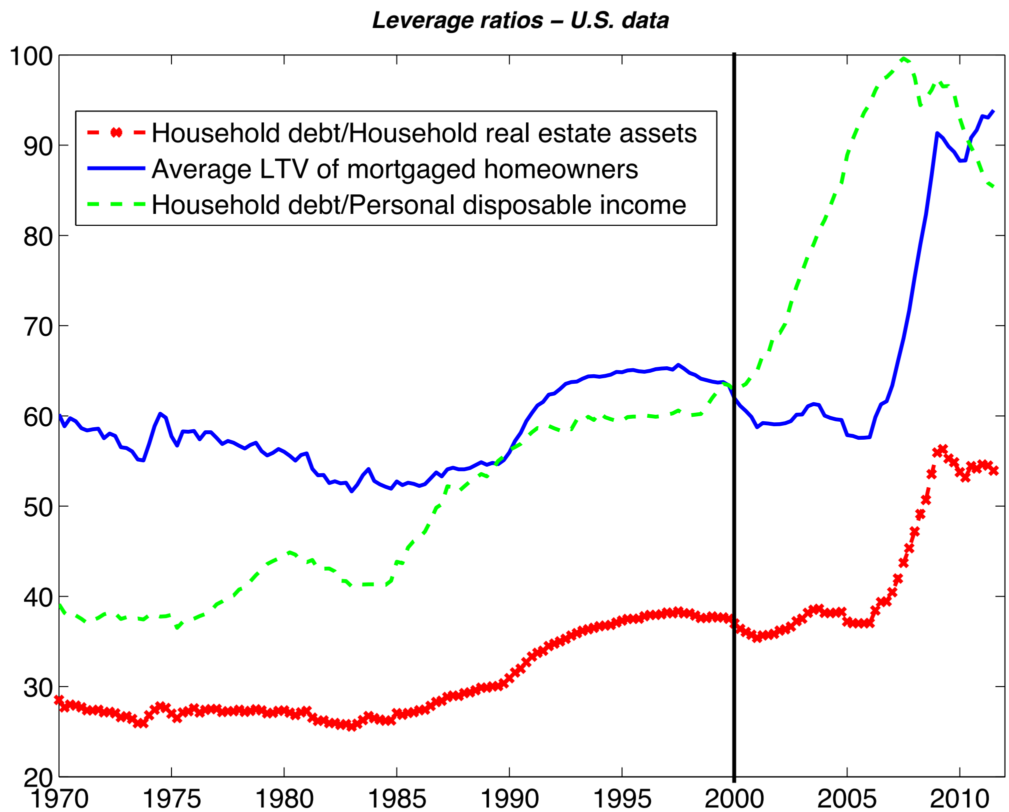

Figure 4: During the U.S. housing boom of the mid-2000s, loan-to-value measures did not signal a significant increase in household leverage because the value of housing assets rose together with liabilities. In contrast, the debt-to-income ratio provided a much earlier warning signal of a potentially dangerous buildup of household leverage.

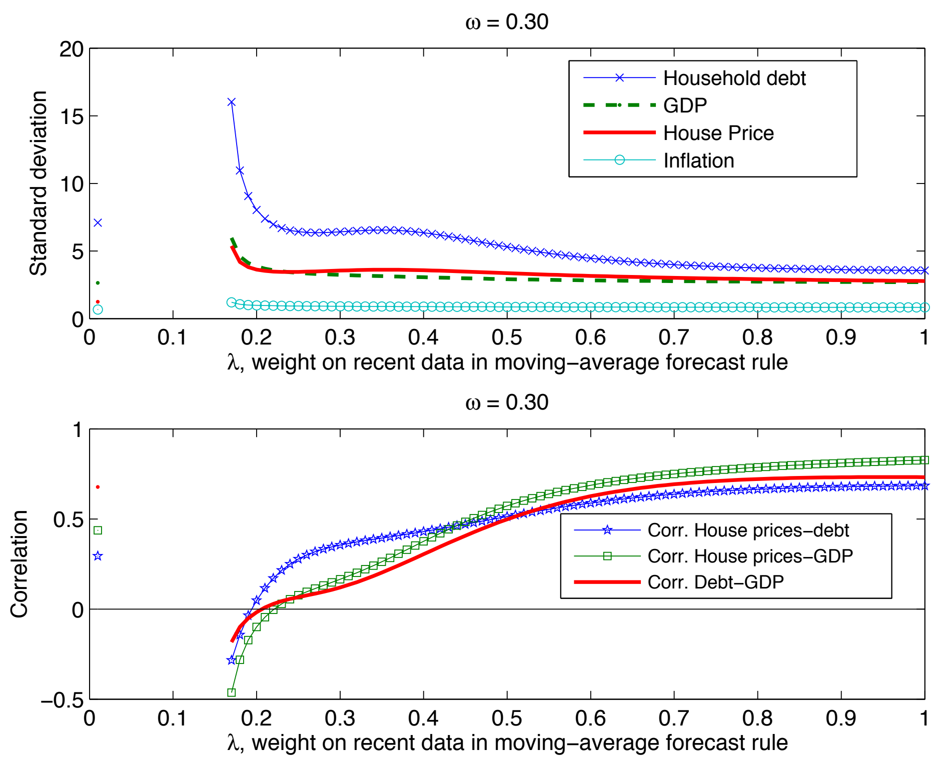

Figure 5: Different combinations of the hybrid expectations parameters ω and λ affect the volatility and co-movement of model variables. Missing values indicate that a unique stable equilibrium does not exist for that combination of ω and λ. The baseline calibration is $\omega = 0.30$ and $\lambda = 0.35$.

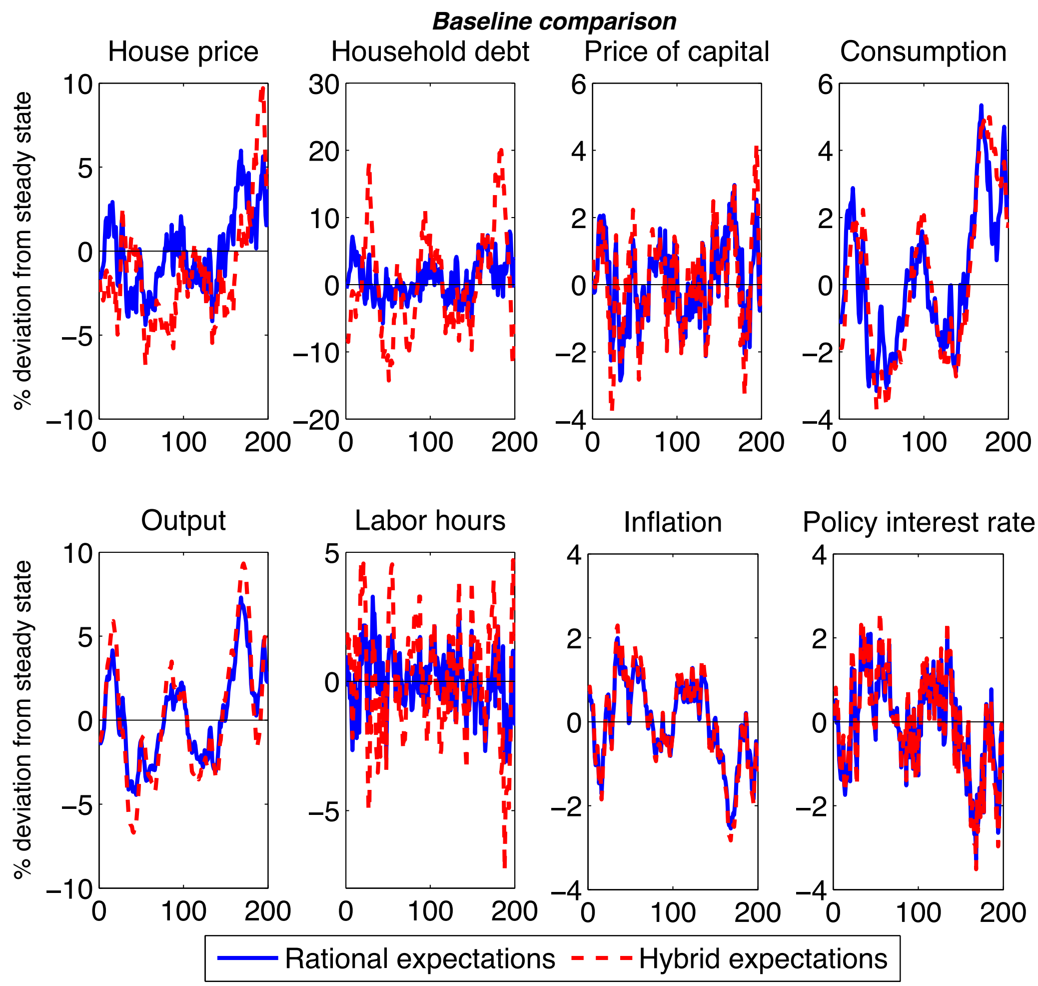

Figure 6: The volatilities of house prices and household debt in the hybrid expectations model are about two times larger than those in the rational expectations model. The price of capital volatility is magnified by a factor of about 1.3. The volatilities of output, labor hours, consumption, and inflation are magnified by factors ranging from 1.1 to 1.9.

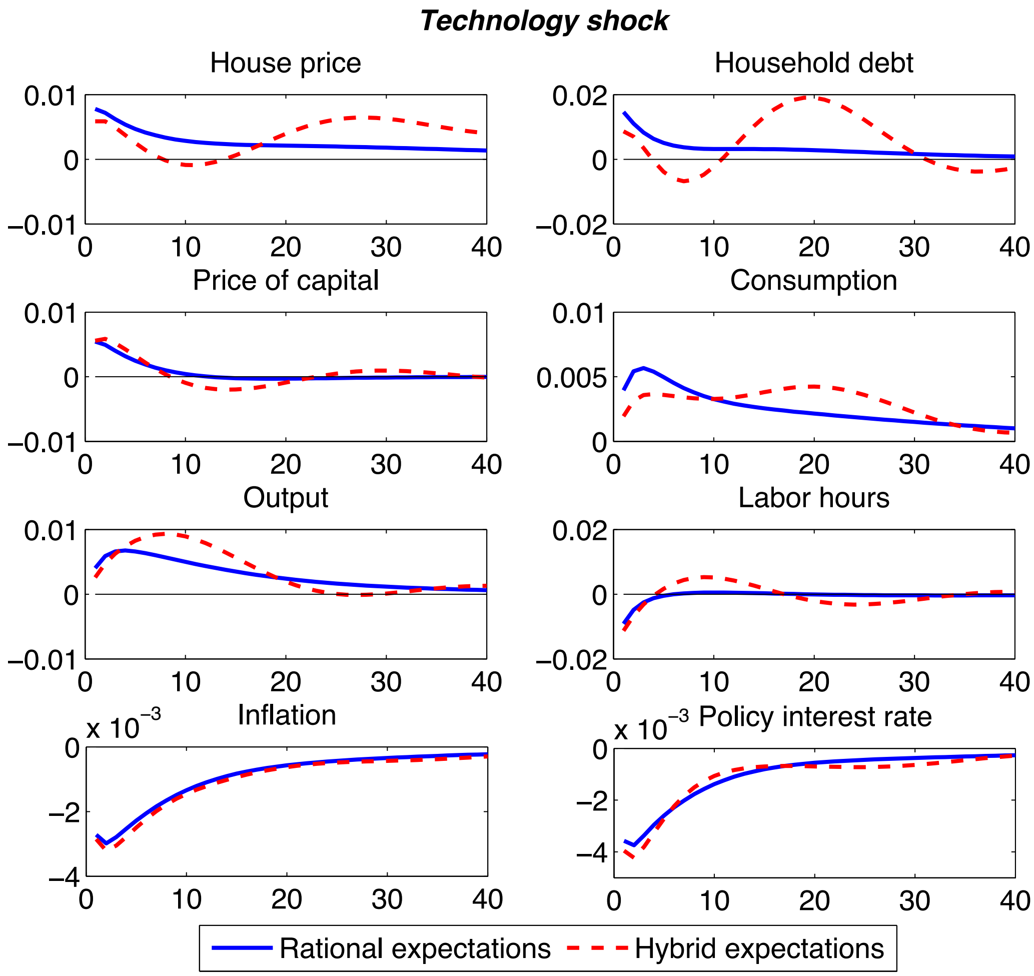

Figure 7: One-standard deviation shock to aggregate productivity. Fluctuations in the hybrid expectations model tend to be more pronounced and longer lasting.

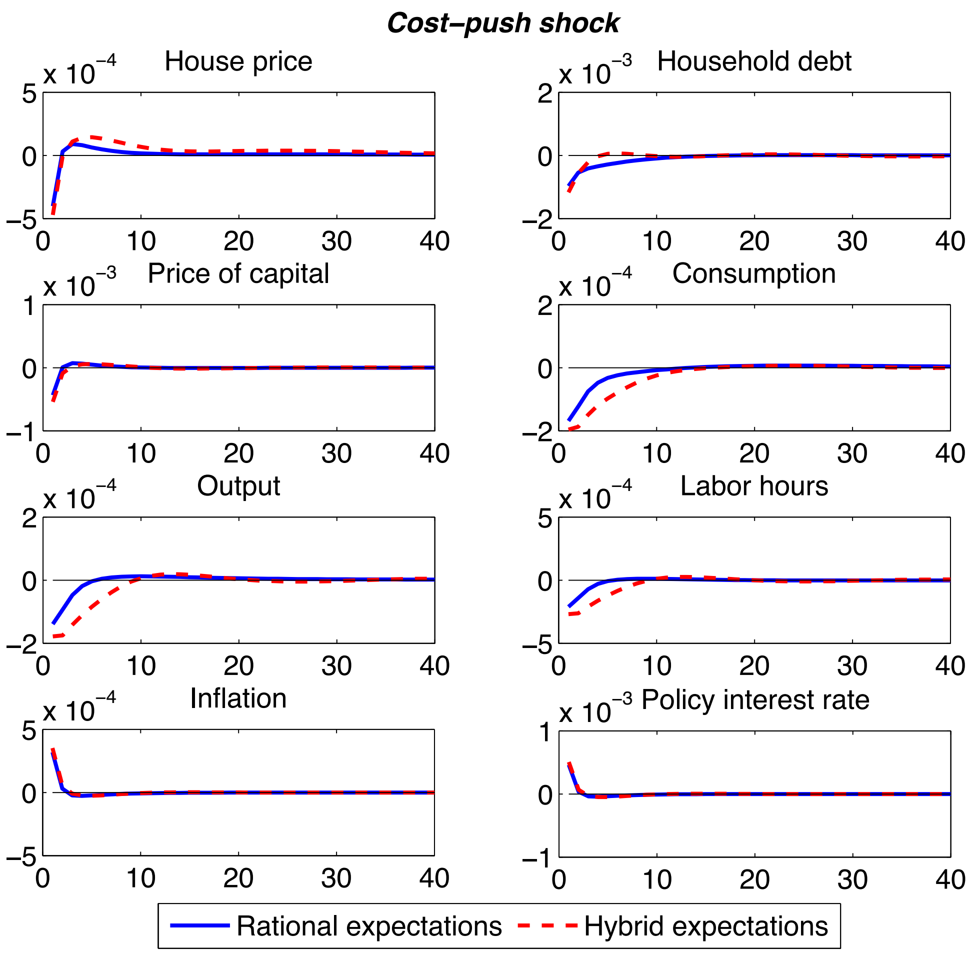

Figure 8: One-standard deviation shock to Phillips curve. Fluctuations in the hybrid expectations model tend to be more pronounced and longer lasting.

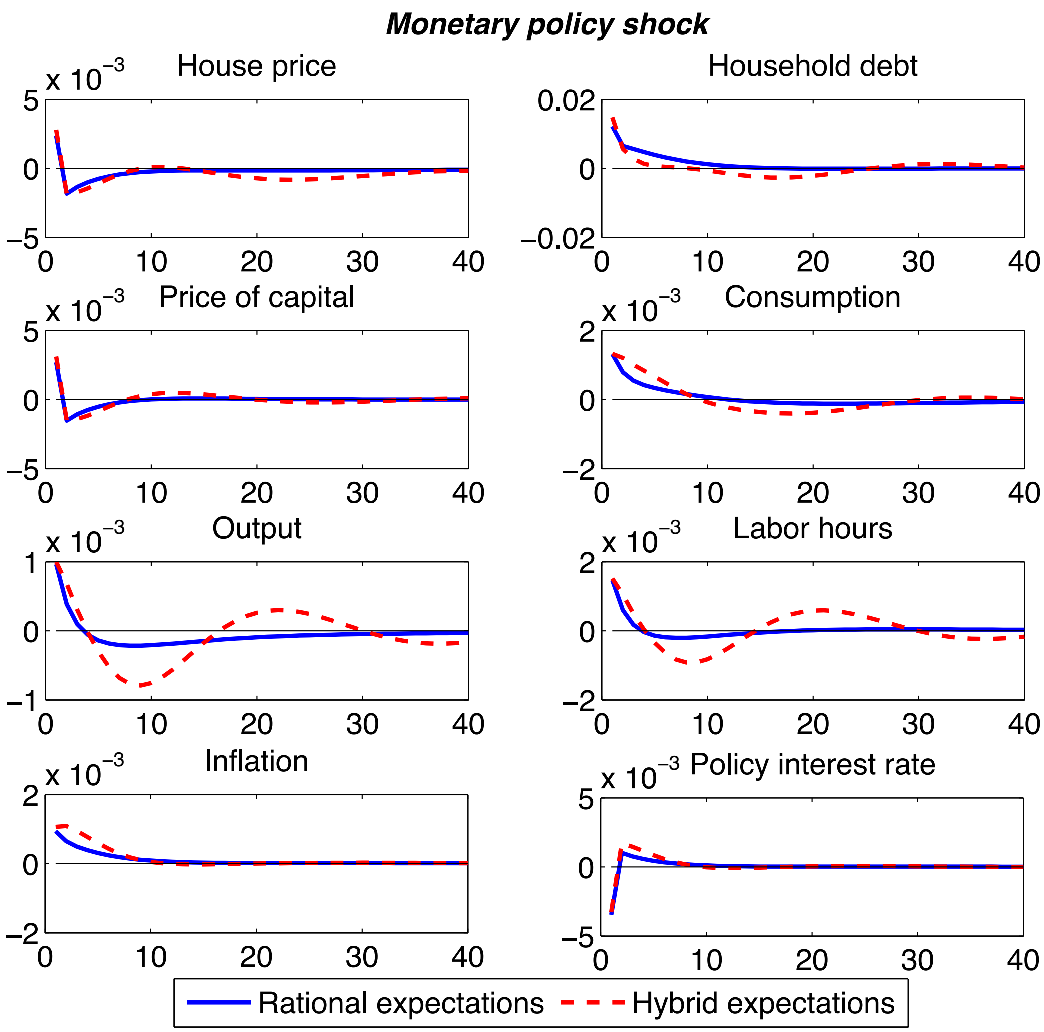

Figure 9: One-standard deviation shock to monetary policy rule. Fluctuations in the hybrid expectations model tend to be more pronounced and longer lasting.

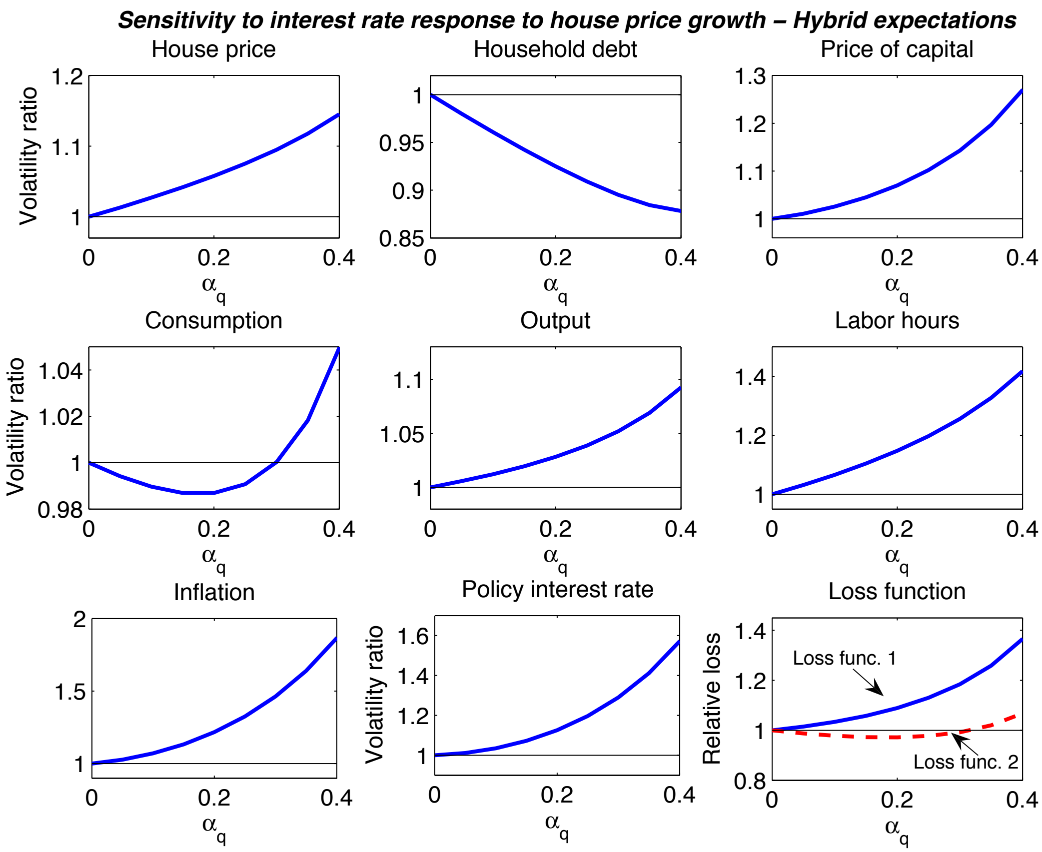

Figure 10: A stronger interest-rate response to house price growth helps to stabilize household debt but it magnifies the volatility of output, labor hours, and particularly inflation. The figure plots ratios relative to the hybrid expectations model with $\alpha_q = 0$. Loss function 1 $= Var(\pi_t) + Var(y_t)$. Loss function 2 $= Var(\pi_t) + Var(y_t) + 0.25\,Var(b_{2,t})$.

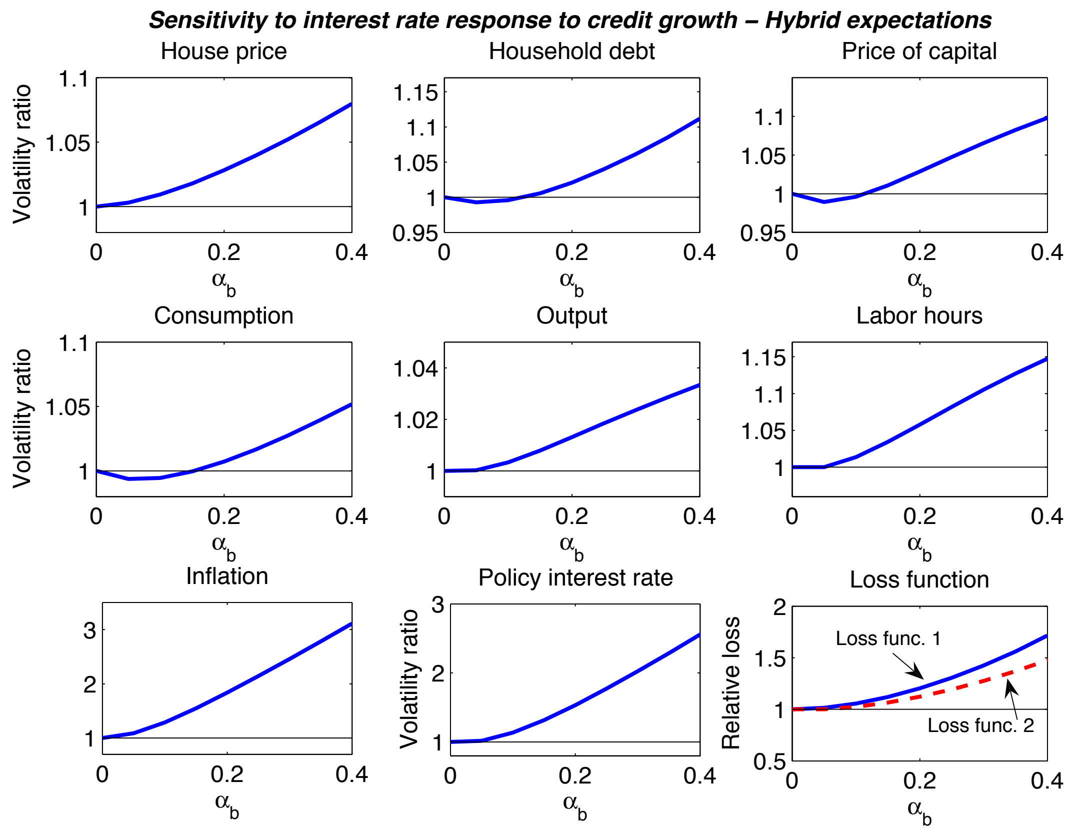

Figure 11: A stronger interest-rate response to credit growth magnifies the volatility of most variables, particularly inflation. The figure plots ratios relative to the hybrid expectations model with $\alpha_b = 0$. Loss function 1 $= Var(\pi_t) + Var(y_t)$. Loss function 2 $= Var(\pi_t) + Var(y_t) + 0.25\,Var(b_{2,t})$.

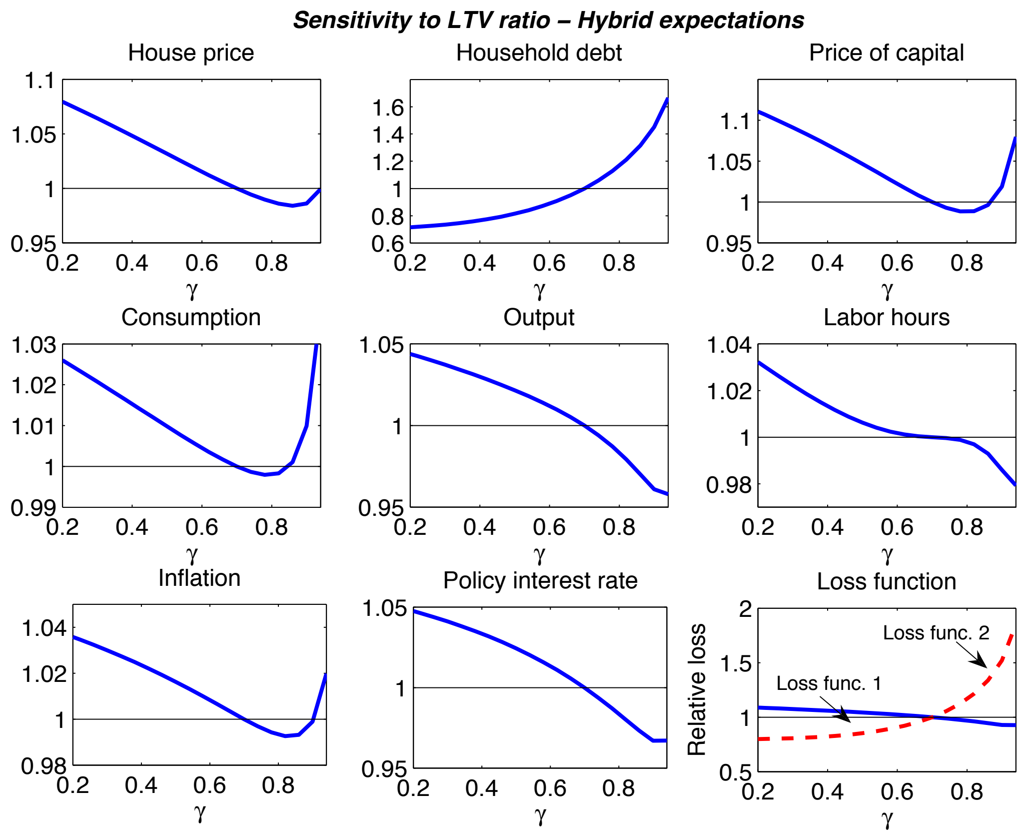

Figure 12: A tightening of lending standards in the form of a reduction in the loan-to-value ratio γ helps to stabilize household debt but it magnifies the volatility of consumption, output, labor hours, and inflation. The figure plots ratios relative to the baseline hybrid expectations model with $\gamma = 0.7$. Loss function $1 = Var\left(\pi_t\right) + Var\left(y_t\right)$. Loss function $2 = Var\left(\pi_t\right) + Var\left(y_t\right) + 0.25\,Var\left(b_{2,t}\right)$.

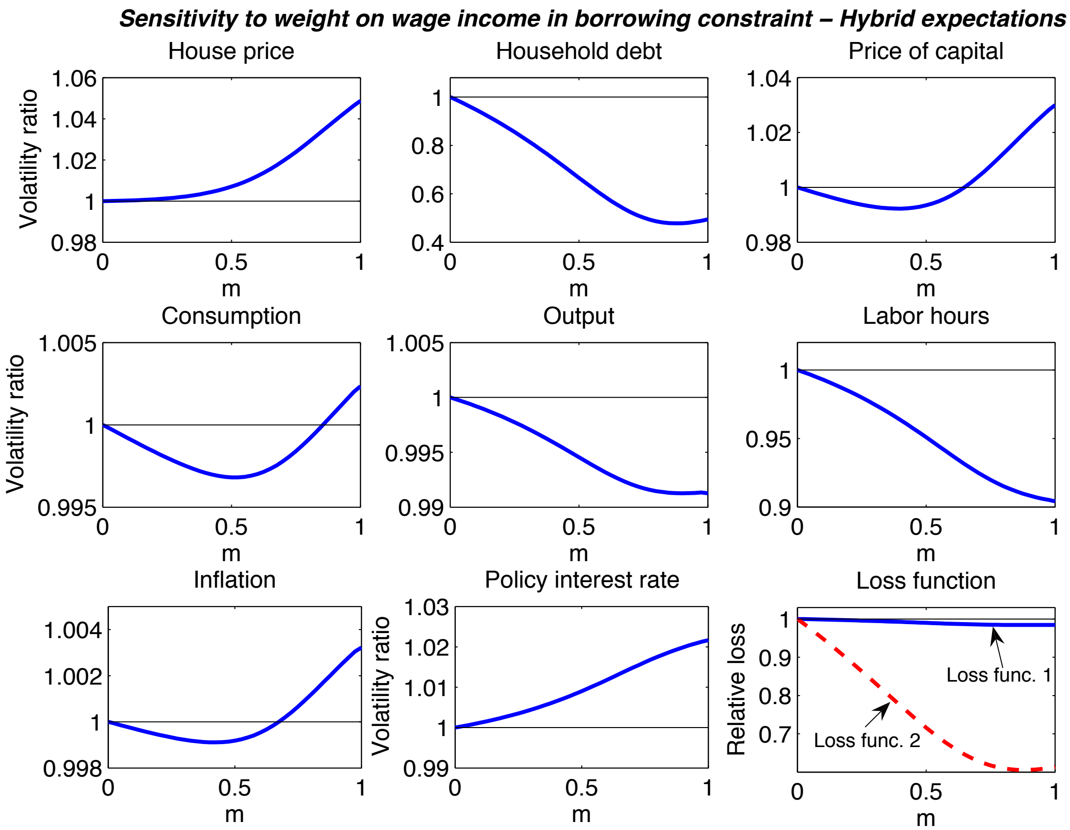

Figure 13: Increasing the weight on the borrower's wage income in the borrowing constraint helps to stabilize household debt while mildy reducing the volatilities of consumption, output, labor hours, and inflation. The figure plots ratios relative to the hybrid expectations model with $m = 0$. Loss function 1 $= Var\left(\pi_t\right) + Var\left(y_t\right)$. Loss function 2 $= Var\left(\pi_t\right) + Var\left(y_t\right) + 0.25\, Var\left(b_{2,t}\right)$.

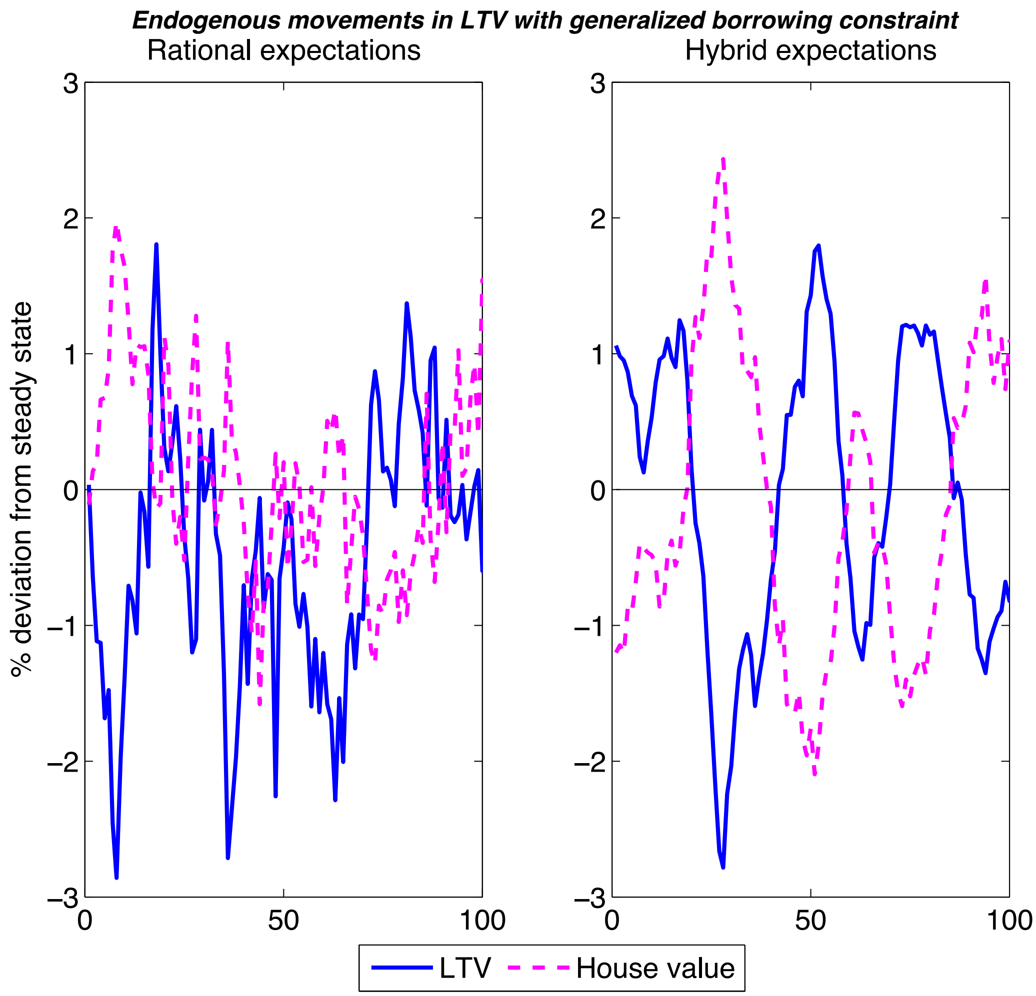

Figure 14: Model simulations using the generalized borrowing constraint (19) which places a substantial weight ($m = 0.5$) on the borrower's wage income. The observed loan-to-value ratio exhibits endogenous countercyclicality which serves as an automatic stabilizer.