Asset Prices and Optimal Monetary Policy Rules *

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Abstract

We construct a New Keynesian DSGE model that features financial frictions, investment frictions, long-run productivity risk, and Epstein and Zin (1989) preferences. The model successfully reproduces key features of both asset prices and macroeconomic quantities. Under this set up, we examine the implications of different monetary policy rules where the central bank responds to inflation, output and asset prices in the presence of productivity shocks, monetary policy shocks, and financial shocks. Our main result suggests that in the presence of these shocks, optimal monetary policy should react to asset prices over and above the inflation and output outlook in order to achieve greater macroeconomic and financial stability. This paper contributes to the current debate on how central bankers ought to respond to asset price volatility, in the context of an overall strategy for monetary policy.

Keywords: Optimal monetary policy rules, Asset pricing, Recursive utility, Long-run risk

JEL classification: E37, E44, E52, E58, G12

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1 Introduction

The two most important objectives of the Federal Reserve are ensuring maximum sustainable employment and price stability. During the past three decades, US monetary policy has been successful in keeping inflation low, stable and close to the Fed's target level of 2%. However, two events, namely, the burst of the dotcom bubble of 2000 and the burst of the sub-prime mortgage bubble of 2007 have shown that large swings in asset prices that coincided with low and stable inflation rates, were followed by large reductions in real economic activity. These events have revived the debate on whether central bankers should respond to asset price misalignments as an overall strategy for monetary policy. While most studies have emphasized strict inflation targeting as optimal monetary policy, these models were incapable of resolving the equity premium puzzle, first studied by Mehra and Prescott (1985), the risk-free rate puzzle (see Weil, 1989), and generating the key characteristics observed in financial data.

This paper attempts to investigate optimal monetary policy by constructing a Dynamic Stochastic General Equilibrium (DSGE) model featuring financial frictions, Epstein and Zin (1989) (recursive) preferences, and long-run productivity risk. Each of these ingredients is important for making the model consistent with key features of macroeconomic and financial data. Our model includes financial market imperfections through the financial accelerator mechanism that amplifies aggregate fluctuations as described in the seminal paper by Bernanke et al. (1999). Recursive preferences help disentangle the elasticity of intertemporal substitution and risk aversion. The success of recursive preferences in production based economies in the presence of endogenous investment and long-run productivity risk can be seen in generating plausible financial dynamics via a sizeable and positive equity premium (see Croce, 2014). Our model has four agents: (1) Households who make consumption and savings decisions under Epstein-Zin preferences, (2) risk neutral entrepreneurs who use a combination of borrowed funds from households and self-financing to invest in capital and produce wholesale output, (3) firms who act as final goods producers and rent capital, labor, and set marginal prices, (4) a central bank that can set monetary policy in response to inflation, output gap, and asset prices.

Our paper can be best described as a combination of Bernanke et al. (1999), Bernanke and Gertler (2000), and Croce (2014). The former two are seminal papers on optimal monetary policy under financial frictions and asset price volatility while the latter study introduces recursive preferences in production based economies in the presence of endogenous investment and long-run productivity risk that generate key characteristics of financial data. To our knowledge, this is the first paper that attempts to bring together these strands of literature by incorporating macro-finance inter-linkages to study optimal monetary policy rules in the presence of asset price volatility.

Under the baseline calibration, our model is able to generate moments of key macroeconomic and financial variables including the volatility of consumption and investment growth, the correlation of consumption and output growth, and the level of the equity premium. We further examine the effects of a short-run productivity shock, long-run productivity shock, monetary policy shock, and financial shock on various macroeconomic and financial variables under a standard Taylor (1993) rule vs. optimal monetary policy rules. Finally, we compute optimal monetary policies under different types of quadratic loss functions of the central bank. Our main result suggests that in the presence of these shocks, optimal monetary policy should react to asset prices over and above the inflation and output outlook in order to achieve greater macroeconomic and financial stability.

The organization of the paper is as follows: Section 2 presents an overview of the related literature; Section 3 presents the DSGE model; Section 4 describes the baseline calibration and the data; Section 5 explains the results and Section 7 concludes.

2 Previous Literature

There is growing literature on optimal monetary policies. Previous studies have analyzed deviations from strict inflation stabilization for a variety of reasons, see Diercks (2016) for an exhaustive review. We focus on the linkages between asset prices and the real economy. Large swings in asset prices can carry huge costs for the real economy through various channels, (wealth effect, Tobin's Q effect, balance sheet effect and expectations) that could endanger the achievement of the goals of the central bank (see Gilchrist and Leahy, 2002).These linkages provide an important argument for why central bankers should view their goals and financial stability as highly complementary.

Standard New Keynesian literature analyzes monetary policy without reference to asset prices.[1] In this traditional framework, asset prices do not appear as an explanatory factor in interest rate determination and consequently in output gap and inflation dynamics. The last two recessions in the United States suggest that asset prices are important for output gap dynamics. In the traditional models, output gap depends mainly on its own future expectations and the real rate of interest (see Walsh (2003), Woodford (2003), Galí (2008)). Moreover, interest rates are determined via a traditional Taylor (1993) rule. The Taylor rule suggests that interest rates should respond to output gap and deviations of inflation from its target level since the goal of the central bank are to ensure price stability and maximum sustainable employment. For instance, in the U.S., the stock market crash of 2001 and the housing market crash of 2007 have shown that achieving financial stability is complementary to the goals of the Federal Reserve. The history of asset-price bubbles has also suggested that asset-price bubbles can have destabilizing effects on the economy during periods with very low and stable inflation. For instance, low inflation was characteristic of the United States in the 1920's and Japan in the 1980's. In both countries, the bust in rising asset prices triggered a very long spell of sluggish economic activity.

There has been a lack of general consensus on what should be the response of the central

[1] A noteworthy exception is the model presented in Bernanke and Gertler (2000)

bank to asset prices. The literature identifies two distinct schools of thought that strongly argue for and against the central bank reaction to financial instability. Bernanke and Gertler (2000) incorporated nonfundamental movements in asset prices into a dynamic macroeconomic framework as in Bernanke et al. (1999). They conclude that it is neither necessary nor desirable for monetary policy to react to changes in asset prices, except to the extent that they signal inflationary or deflationary pressures. They also suggest that a flexible inflation-targeting framework is effective in achieving macroeconomic and financial stability. Cecchetti et al. (2000), Cecchetti et al. (2002), Cecchetti (2003) argue that the central banks should react to asset-price bubbles by using the same framework. They show that a central bank concerned about stabilizing inflation around a specific target will achieve superior performance by adjusting its policy instruments, not only in response to future forecasts of inflation and output gap but to asset prices as well. The key difference in their results vs. Bernanke and Gertler (2000) lies in different assumptions about what shocks are present and exactly what the monetary authorities are allowed to observe as shocks.[2] Lansing (2008) shows that the inclusion of the stock market variables significantly improves the fit of the augmented Taylor rule, particularly from 2006 through the end of the data sample in September 2008.[3] Bordo and Jeanne (2002) point to the risks of using simple monetary policy rules with two or three variables as the guide for monetary policy. They argue that the linkages between asset prices, financial instability, and optimal monetary policy are highly complex because they are inherently nonlinear, and recommend a need for some discretionary judgement over the probability of extreme events.

Borio and Lowe (2002) argue that financial imbalances can build up in low inflation environments and thus it is appropriate for policy to respond to contain these imbalances.

[2] Bernanke and Gertler (2001) later attribute their findings to the use of a misleading metric in the comparison between policy rules.

[3] The augmented Taylor rule includes two additional explanatory variables: (1) the percentage change in the S&P 500 stock index over the prior 12 months, and (2) the prior-month level of the S&P 500 stock index. This ensures that the direction of causation runs from the stock market to the funds rate, and not vice versa. However, he finds that despite integrating information on the stock market, the actual funds rate remained below the estimated policy rule path from 2003 to 2005.

They present empirical evidence and suggest that while identifying asset bubbles in real time maybe difficult for central banks, it may be possible if central banks expanded their outlook beyond asset prices to include other variables like sustained credit expansion, booming stock or housing prices, and high levels of investment that often precede periods of financial stress.[4] Christiano et al. (2010) used historical data to show that low inflation environments have been characteristic of stock market booms. They use model simulations to show that an interest rate rule that is too narrowly focused on inflation causes financial distress and destabilizes the macroeconomy. They suggest that a welfare enhancing monetary policy rule, one that allows an independent role for credit growth would reduce the volatility of output and asset prices.

If the central bank is trying to prick an asset bubble, then it should raise interest rates in response to rising asset prices. Similarly, if asset prices are below warranted levels, the central bank should lower interest rates. This preemptive action by the central bank may result in greater economic stability. This phenomenon is referred to as "leaning against the wind" in the literature (LAW).[5] Since both periods preceding the 2001 and 2007-09 recessions were characterized by substantial credit growth, a few recent studies have investigated the costs and benefits of LAW policies. A benefit of a higher policy rate in response to rapid credit growth is that it may reduce the likelihood of a crisis and mitigate its adverse effects on the economy in case a crisis occurs. The costs of a higher policy rate is that it may result in a decrease in economic activity and inflation relative to target. Svensson (2016) has shown that the marginal costs of LAW policies outweigh marginal benefits in a model where

[4] They argue that asset-price bubbles tend to be associated with very high investments and a build up of debt. As asset values appreciate the value of the collateral that facilitates the accumulation of debt increases. Thus, balance sheets look unrealistically healthy as the appreciated asset values offset the build up of debt. When the bubble busts, there is a deterioration of net worth that leads to financial distress. Since appreciating asset prices have a direct wealth effect on consumption, a Tobin's Q effect, and balance sheet effects on investment, an asset burst can have substantial effects on real output and inflation. Also, see Christiano et al. (2007) that describes how a credit boom may provide useful information for monetary policy.

[5] LAW policies are defined as "a monetary policy with a somewhat higher policy interest rate than what is consistent with just stabilizing inflation around an inflation target and unemployment around its estimated long-run sustainable rate without taking any effects on financial stability into account", see Svensson (2016).

the quadratic loss of the central bank is a function of the unemployment gap only. Ajello et al. (2016) examine optimal monetary policy in a New Keynesian framework in which the probability of a financial crisis depends on credit conditions. Their result indicates that a robust central bank will respond aggressively to financial instability when the probability and severity of financial crises are uncertain. They use a quadratic loss function that consists of inflation and output gap, consistent with the dual mandate. Gerdrup et al. (2016) extend Ajello et al. (2016)'s study by endogenizing both the probability of a financial crisis and the severity of the crisis. They find that benefits of LAW policies in terms of a lower frequency of severe financial crisis exceed its costs in terms of higher volatility in output and inflation in normal times. Our study is in the same vein as a previous study by Gilchrist and Saito (2006) and a recent study by Dierckx (2016). The former incorporates learning along with financial frictions for the evaluation of alternative monetary policy rules. The latter examines the welfare implications of monetary policy by constructing a DSGE model that does properly account for asset pricing facts. However, the role of the financial accelerator is absent in their model.

While the studies we mentioned contribute immensely to the literature on monetary policy and asset prices, these studies lack either one or both of the following: (1) rely on simulations and do not study "optimal" monetary policy rules under asset price volatility (2) suffer from the equity premium puzzle & the risk-free rate puzzle and therefore do not match financial data. Our study helps to close this gap in the literature.

3 Model

Our model is a dynamic stochastic general equilibrium model with a financial accelerator mechanism (see Bernanke et al., 1999) featuring long run-risk and recursive preferences as in Croce (2014). The basic structure of the model is as follows: There are four types of agents, namely households, entrepreneurs, retail firms, and a central bank. Households and entrepreneurs are introduced to motivate lending and borrowing. Households make consumption and saving decisions under recursive preferences. The risk neutral entrepreneurs, who rent capital and hire labor, produce wholesale output using both, borrowed funds from households and their entrepreneurial wealth or "net worth". Retail firms act as final goods producers, and set marginal prices. Having retail firms ensures that price rigidity exists in the economy which is essential for the short-run non-neutrality of monetary policy. Finally, a central bank that can set monetary policy in response to inflation, output growth and asset price gap is included to close the model.

3.1 Households

We assume representative households that live forever and have Epstein and Zin (1989) preferences as follows:

$$V_t = \left[(1-\beta)\tilde{C}_t^{1-1/\psi} + \beta(\mathcal{R}_t(V_{t+1}))^{1-1/\psi}\right]^{\frac{1}{1-1/\psi}}, \tag{1}$$

where

$$\mathcal{R}_t(V_{t+1}) = E_t[V_{t+1}^{1-\gamma}]^{1/(1-\gamma)}.$$

The parameter γ is the Arrow-Pratt coefficient of constant relative risk aversion (CRRA), ψ is the elasticity of intertemporal substitution (EIS), and β measures the subjective time discount rate under certainty. The function reduces to a monotone transformation of the standard power utility function for $\psi = \gamma^{-1}$.

The consumption bundle aggregates consumption, C_t and leisure, l_t, according to:

$$\tilde{C}_t = [\varphi C_t^{1-1/\xi} + (1-\varphi)(A_{t-1}l_t)^{1-1/\xi}]^{1/(1-1/\xi)},$$

where A represents aggregate productivity and φ is the weight that determines the average share of hours worked. Leisure is multiplied by productivity to ensure balanced growth even if consumption-labor elasticity, ξ, is different than 1, and can be considered as an adjustment for standards of living.

The time t budget constraint of the household is

$$P_t C_t + B_{t+1} = R_t^f B_t + W_t N_t + Z_t, \tag{2}$$

for t=0,1,2..., where P_t is the nominal price of final goods, B_{t+1} is the quantity of nominal one period bonds, R_t^f is the gross one-period nominal interest rate set at time $t-1$ by the monetary authority. W_t represents the nominal wage rate received by supplying labor N_t. Z_t are the dividends income received from the ownership of retail firms.

The household's intertemporal condition is given by

$$1 = E_t\left[\mathcal{M}_{t+1}\frac{P_t}{P_{t+1}}R_{t+1}\right], \tag{3}$$

where

$$\mathcal{M}_{t,t+1} = \beta\left(\frac{C_{t+1}}{C_t}\right)^{-1/\xi}\left(\frac{\tilde{C}_{t+1}}{C_t}\right)^{1/\xi-1/\psi}\left(\frac{V_{t+1}}{\mathcal{R}_t(V_{t+1})}\right)^{1/\psi-\gamma} \tag{4}$$

is the real stochastic discount factor.[6]

The intra-temporal condition is as follows:

$$\frac{\partial \tilde{C}_t}{\partial l_t}/\frac{\partial \tilde{C}_t}{\partial C_t} = \frac{W_t}{P_t}. \tag{5}$$

The intra-temporal optimality condition governs the trade-off between consumption and leisure and can be interpreted as the labor supply schedule.[7] This condition equates the

[6]The stochastic discount factor is a stochastic process $M_{t,t+s}$ such that for any security with payoff x_{t+1} at time $t+1$ the price of that security at time t is $E_t[M_{t,t+1}x_{t+1}]$

[7]Ultimately, the real wage is given by $\frac{W_t}{P_t} = (1-\alpha)\frac{Y_t}{N_t}$.

marginal rate of substitution between consumption and leisure to the marginal product of labor.

3.2 Entrepreneurs

Entrepreneurs are assumed to be risk-neutral, have finite horizons, and accumulate capital each period to use in the next period. Capital and hired labor are then used to produce wholesale output. The continuum of perfectly competitive entrepreneurs can be described by the following constant returns to scale aggregate neoclassical production function:

$$Y_t = K_t^{\alpha}[A_t N_t]^{1-\alpha}, \tag{6}$$

where Y_t is the aggregate output of wholesale goods, K_t is the fixed stock of capital purchased by entrepreneurs in time t-1 and carried into time t, N_t is labor and A_t represents aggregate technology.

The next period capital stock, K_{t+1} is based on the current capital stock depreciated at rate, δ, and the current investment flow, I_t, subject to a convex adjustment cost G_t. The capital stock evolves according to

$$K_{t+1} = (1-\delta)K_t + I_t - G_t K_t. \tag{7}$$

We follow Jermann (1998) to allow for the presence of convex adjustment costs in capital accumulation so that the supply curve of new capital is not perfectly flexible. This makes the price of new capital time varying. The price of new capital increases when there is an increase in the aggregate investment in the economy. The cost function, $G_t(\cdot)$ is represented by

$$G_t = \frac{I_t}{K_t} - \left[\frac{b}{1-a}\left(\frac{I_t}{K_t}\right)^{1-a} - c\right]. \tag{8}$$

In addition, each entrepreneur faces a survival probability ϕ_{nw} each period. This assumption is made to ensure that the entry and exit of firms is motivated in our model as well as to prevent the entrepreneurs to be fully capable of self-financing. In each period t, entrepreneurs who survive, acquire physical capital, K_t, whereas the ones who don't, consume their left over resources before exiting. At the end of period t, after the production of wholesale goods, the entrepreneur purchases capital K_{t+1} from retail firms at price Q_t. Physical capital acquired in period t is then used in combination with hired labor to produce the wholesale goods in the next period.

The acquisition of physical capital comes from two sources: entrepreneurial wealth or "net worth" (internal finance) and borrowing (external finance). The entrepreneur finances the purchase of capital $Q_t K_{t+1}$ partly with net worth NW_{t+1} and partly by debt finance B_{t+1} from households:

$$Q_t K_{t+1} = NW_{t+1} + \frac{B_{t+1}}{P_t}$$

We assume that entrepreneurs sell all their output to retailers. If $1/X_t$ is the relative price of wholesale goods to retail goods, then X_t is the gross markup of retail goods over wholesale goods.

The Cobb-Douglas production technology implies that the rent paid to a unit of capital in $t+1$ for the production of wholesale goods is:

$$\frac{1}{X_{t+1}} \frac{\alpha Y_{t+1}}{K_{t+1}}.$$

The entrepreneur's decision to purchase capital depends on the expected return on capital and the expected marginal cost of finance.[8] The expected gross return to capital from period t to $t+1$ depends on the marginal profit from the production of wholesale goods and the capital gain and is given by:

[8] The expected gross return on capital varies inversely with the level of investment characterizing diminishing returns.

$$R_{t+1} = \frac{\frac{1}{X_{t+1}}\frac{\alpha Y_{t+1}}{K_{t+1}} + Q_{t+1}(1-\delta)}{Q_t}$$

with $Q_t = 1/G'$.

The net worth of entrepreneurs is equal to the profits accumulated from previous capital investment[9]. The aggregate net worth of entrepreneurs at the end of period t is the sum of the equity held by entrepreneurs who survive from the previous period:

$$\begin{aligned} NW_{t+1} &= \phi_{nw}\left[R_t Q_{t-1} K_t - E_{t-1} R_t^f \frac{B_t}{P_{t-1}}\right] \\ NW_{t+1} &= \phi_{nw}\left[R_t Q_{t-1} K_t - E_{t-1} R_t^f (Q_{t-1} K_t - NW_t)\right] \end{aligned}$$

Additionally, we define ς_t as the ratio of the entrepreneurs cost of external finance to the cost of internal finance:

$$\varsigma_t = \frac{E_t R_{t+1}}{E_t R_{t+1}^f \frac{P_t}{P_{t+1}}},$$

we can see that the net worth of entrepreneurs is inversely proportional to the cost of external finance.[10] Higher levels of net worth allow for increased self-financing and reduce the external finance premium faced by the entrepreneur in equilibrium.[11]

$$\varsigma_t = \varsigma\left(\frac{Q_t K_{t+1}}{NW_{t+1}}\right)$$

where $\varsigma(\cdot)$ is an increasing function for $NW_{t+1} < Q_t K_{t+1}$. This denotes the supply curve for investment and shows the relationship between the external finance premium to the

[9] For tractability purposes, we assume that entrepreneurs supply their labor inelastically, and we normalize the total entrepreneurial labor to unity.

[10] The ratio is equal to one in the absence of financial market imperfections, since there is no external finance premium

[11] We could think of a financial intermediary playing a trivial role as a competitive lender in the model. The financial intermediary could facilitate the determination of the entrepreneur's demand for capital and negotiate the terms of external finance.

financial condition of the entrepreneurs.

Changes in asset prices are thus responsible for major fluctuations in the real return on capital that cause changes in entrepreneurial net worth and in the external finance premium. Entrepreneurs who are exiting the market in period t are assumed to consume their left over capital stock:

$$C_t^e = (1 - \phi_{nw}) \left[R_t Q_{t-1} K_t - E_{t-1} R_t^f (Q_{t-1} K_t - NW_t) \right]$$

where C_t^e represents entrepreneurial consumption.

Productivity

The law of motion for productivity growth consists of two components: (i) short-run risk and (ii) long-run risk. If we consider the productivity shock, A_t, we can express its law of motion as a process with stochastic parameters that depend on the state of the economy as following:

$$\Delta \log A_t = \mu + x_t + \sigma_a \varepsilon_{a,t} \quad (9)$$

$$x_t = \rho x_{t-1} + \sigma_x \varepsilon_{x,t} \quad (10)$$

$$\varepsilon_{a,t}, \varepsilon_{x,t} \quad \text{i.i.d} \sim N(0,1)$$

where x refers to the (unobservable) long run risk component in productivity growth. Short-run productivity shocks, $\varepsilon_{a,t}$, affect contemporaneous output directly, but they have no effect on future productivity growth. Shocks to long-run productivity, represented by $\varepsilon_{x,t}$, carry news about future productivity growth rates and are meant to be persistent.

3.3 Retail Firms

Entrepreneurs produce wholesale goods in competitive markets as described above and sell their output to retail firms who are monopolistic competitors. Retail firms buy goods from entrepreneurs, differentiate them (costlessly), then re-sell them to households. The monopolistic power of retailers provides the source of price rigidity in the economy which in turn is responsible for making monetary policy non-neutral in the short run. We assume that profits from retail activity are rebated lump-sum to households.

We assume a continuum of monopolistically competitive retail firms, $Y_t(i)$ indexed by $i \in [0,1]$ which sell a continuum of differentiated goods at nominal price, $P_t(i)$. Final goods, Y_t are the composite of individual retail goods

$$Y_t \equiv \left(\int_0^1 Y_t(i)^{1-\frac{1}{\varepsilon}} di \right)^{\frac{\varepsilon}{\varepsilon-1}}, \tag{11}$$

and the corresponding price index, P_t, is given by

$$P_t \equiv \left(\int_0^1 P_t(i)^{1-\varepsilon} di \right)^{\frac{1}{1-\varepsilon}}. \tag{12}$$

Households and entrepreneurs demand final goods. Each retail firm faces an isoelastic demand curve given by

$$Y_t(i) = \left(\frac{P_t(i)}{P_t} \right)^{-\varepsilon} Y_t. \tag{13}$$

The retail firm is then able to choose the sale price $P_t(i)$, taking the demand curve and the price of the wholesale good, P_t^w as given. Following Calvo (1983), we introduce price rigidity into our model. Each retail firm sets price with probability $1-\upsilon$, independently of the time elapsed since the last price adjustment. Therefore, in each period, a fraction $(1-\upsilon)$ of retailers reset their prices, while the remaining fraction υ keep their prices unchanged. The real marginal cost to the retailers of producing a unit of retail goods is the price of wholesale goods relative to the price of final goods, P_t^w/P_t.

Each retail firm faces the same decision problem and, if allowed to re-optimize, sets the same price P_t^* to maximize the expected present discounted value of future profits. Basically, the firm reoptimizing in period t will choose the price P_t^* that maximizes the current market value of the profits generated while that price remains effective. Formally,

$$max \quad \sum_{k=0}^{\infty} \upsilon^k E_t(\mathcal{M}_{t,t+k} \frac{P_t^* - P_{t+k}^w}{P_{t+k}} Y_{t+k}^*),$$

where $\mathcal{M}_{t,t+k}$ is the stochastic discount factor that retailers take as given. The aggregate price evolves according to,

$$P_t = \left[\upsilon P_{t-1}(i)^{1-\varepsilon} + (1-\upsilon)(P_t^*)^{1-\varepsilon}\right]^{\frac{1}{1-\varepsilon}}.$$

Combining the two equations above gives the Phillips curve that relates the the current inflation to the current real marginal cost and the expected inflation.

3.4 Adding exogenous asset price bubbles

To examine the performance of different monetary policy rules in the presence of asset price bubbles, we follow the set up introduced by Bernanke and Gertler (2000). Our model is augmented to allow for exogenous bubbles or nonfundamental movements in asset prices.[12] The "financial accelerator" mechanism in our model implies that as financial conditions of entrepreneurs improve, the external finance premium decreases which can have amplifying effects on real variables in the economy. An asset price bubble tends to improve the balance sheets of entrepreneurs thereby decreasing the external finance premium and stimulating investment spending. This increase in investment demand may further put an upward pressure on asset prices and spending. The conduct of monetary policy is extremely important under this framework. An expansionary monetary policy (or policy easing) tends to reduce the external finance premium and raises asset prices. By allowing for asset prices to deviate from their fundamental path, we can examine the performance of alternate monetary policy rules on various real variables in the economy.

The fundamental value of capital, Q_t, is given by the present value of dividends is expected

[12]The term bubbles is used loosely to represent a temporary shock to the fundamental value of capital. This can be due to liquidity trading, irrational exuberance or other behavioral biases.

to generate:

$$Q_t = E_t[D_{t+1} + (1-\delta)Q_{t+1}]/R^q_{t+1}$$

where δ is the physical depreciation of capital, D_{t+1} are dividends and R^q_{t+1} is the relevant stochastic gross discount rate.

Under our experiment, the non-fundamental price of capital, S_t, is allowed to differ from the capital's fundamental value, Q_t. Whenever $S_t - Q_t \neq 0$, an exogenous bubble exists.

Overall, the non fundamental price of capital equals the sum of the fundamental component of asset price and the bubble component of asset price which is represented by a financial shock, ϵ^f_t.

$$S_t = Q_t + \epsilon^f_t$$

The asset price bubble component is modeled as being exogenous, Bernanke and Gertler (2000). This specification is kept arbitrary because economists do not have a consensus on empirical models of asset price bubbles. According to this set up, we can allow for positive or negative bubbles. The bubble is assumed to last only one period. There are numerous possibilities that can be considered for how the bubble component may evolve independently of other variables in the economy, see Filardo (2001).[13] The bubble can affect the real economy in two ways (1) via a wealth effect on consumption (2) via the financial accelerator effect on balance sheets (investment channel). The latter channel is considered to be dominant.[14] In our model, the sign of the shock is negative which corresponds to a fall in the current price of capital, similar to what is observed during a stock market bubble.

[13]For instance, we could allow for serial correlation in the shock process so the bubble dies out after a certain number of periods rather than immediately. However, for simplicity, we restrict ourselves to a one period shock.

[14]As in Bernanke and Gertler (2000), we rule out the possibility of arbitrage, that is firms will not build new capital and sell it at the new market price.

3.5 Central Bank

The central bank is assumed to set nominal interest rate according to a Taylor (1993) type rule. An augmented version of the Taylor rule suggests that interest rates are set in response to changes in inflation, output gap, and the asset price gap.

$$r_t = \phi_\pi \pi_t + \phi_y y_t + \phi_f sq_t + \epsilon_t^m \tag{14}$$

The parameters ϕ_π, ϕ_y and ϕ_f are coefficients on inflation, output gap, and asset price gap, sq_t. The monetary policy shock is given by ϵ_t^m. The asset price gap is measured as the difference between the current price of capital and the expected price of capital after an exogenous shock.[15] In our benchmark model, we consider a monetary policy rule that only reacts to inflation and output gap. In section 6, we consider optimal policy rules under various specifications of the central bank's loss function.

3.6 Equilibrium

Beyond the labor market clearing, we require that supply matches demand in capital markets and goods markets. The equilibrium in these two markets is given as follows:

In the capital market,

$$K_{t+1} - (1-\delta)K_t = \phi_{nw} I_t$$

In the goods market, total output is the sum of household consumption, entrepreneurial consumption and investment across all entrepreneurs.

$$Y_t = C_t + (1-\phi_{nw})C_t^e + \phi_{nw} I_t$$

[15] The asset price gap is defined as $sq_t = S_t - E_t Q_{t+1}$. This gap may also occur due to other shocks in our model since they have the potential to affect the fundamental price of capital.

4 Benchmark calibration

In our benchmark parametrization we calibrate the model to an annual frequency following the mainstream literature. Table 1 summarizes these parameters. For our preference parameters we closely follow Croce (2014): investor risk aversion is set to $\gamma = 10$; investor elasticity of intertemporal substitution (EIS) is given by $\psi = 2$, and the subjective discount factor is given by $\beta = 0.9767$.[16] The consumption labor elasticity, ξ, is set to one while the weight that determines the average share of hours worked, φ, is set to 0.2, to match the value of the share of hours worked according to the recent estimates reported by the American Time use survey ($33\% - 40\%$, in the steady state).

Among our technology parameters, the annual capital depreciation rate, δ is 6% which corresponds to a monthly depreciation rate of 0.5%. The parameter, α, is set to 0.34 to match the capital income share. The inverse of the elasticity of the adjustment cost function, a, is set to 0.142 to make investment reasonably volatile. The survival probability of entrepreneurs is 88% and their share in the economy is 10%, in line with Bernanke et al. (1999).

On the productivity side, we again refer to Croce (2014). The drift parameter, μ, is set to obtain an annualized average output growth of 1.8%, while σ_a is set to 1% yielding an annual volatility of output growth of 3.35%. Following the long run risk literature started with Bansal and Yaron (2004), the long-run component of productivity risk, x_t, is calibrated to be small and persistent. The parameter, ρ, is set to 0.8 implying an annual persistence in line with Croce (2014). Finally, to ensure that the long-run component is small enough, we impose $\sigma_x \times 10\% = \sigma_a$. The benchmark monetary policy rule is assumed to be a standard Taylor rule as in Galí (2008).[17] The financial shock and monetary policy shock are both assumed to have a a standard deviation of 1%.

[16] d'Addona and Brevik (2010) have shown that an EIS larger than one is one of the key ingredients required to produce a sizeable equity premium.

[17] Empirical interest rate rules for the U.S. are generally estimated using interest rate, inflation, and output data expressed in annual rates.

Table 1: Baseline calibration

Parameter	Description	Value
Panel A: Preferences		
β	Subjective discount factor	0.9767
ψ	Elasticity of intertemporal substitution	2
γ	Risk aversion	10
ξ	Consumption -labor elasticity	1
φ	Consumption-labor CES weight	0.2
Panel B: Technology		
α	Capital share in income	0.34
δ	Depreciation rate of capital stock	0.06
a	Adjustment cost parameter	0.142
ϕ_{nw}	Survival probability of entrepreneurs	0.88
η	Share of entrepreneurs in the economy	0.1
Panel C: Productivity		
ρ	Persistence of long run-shock	0.8
μ	Long-run mean of productivity	0.0018
Panel D: Policy		
ϕ_{pi}	Sensitivity of policy rate to inflation	1.5
ϕ_y	Sensitivity of policy rate to output gap	0.5
ϕ_f	Sensitivity of policy rate to asset price gap	0

5 Results

We summarize model vs. data moments in Table 2. The data used to assess the model behavior in terms of first and second moments span from the beginning of the year 1952 to the end of 2014. The dataset is expressed in real per capita terms with an annual frequency. The financial series (prices and dividends) are drawn on the S&P 500 composite index, while the risk-free rate is the yield on the 1-year Treasury bill. These series are taken from Robert J. Shiller's webpage (Shiller Data) and the Federal Reserve Economic Data. The main economic time series are downloaded from the Bureau of Economic Analysis. Consumption is measured as the annual real total personal consumption expenditure (NIPA table 2.3.6, line 1), GDP as annual real gross domestic income (NIPA table 1.1.6, line 1), and investment in physical capital as annual non-residential fixed investment (NIPA table 5.3.5, line 2).

When compared with the US postwar data, our model matches the second moments of the annual growth rate of consumption and investment extremely well. Our model slightly overestimates the volatility ratio of production investment to output ($\sigma\Delta I/\sigma\Delta Y$) and the ratio of consumption to output volatility. When we analyze co-movements of relevant macro variables, the implied correlation between consumption and output growth rates is also in line with the data (cf. sixth line, of table 2), while the model-implied correlation between the excess return on the equity claim and consumption growth rates is largely overestimated by the model. This unwelcomed result is partially balanced by the capability of the model to replicate the equity premium (5.8% is the model-implied equity premium vs a 6% in the data), at the expenses of a substantial lower volatility (6% is the model-implied equity premium volatility vs. a 16% in the data).[18]

The somehow unsatisfactory performance of the model in terms of output volatility is not new in the literature, see Jermann (1998) and Tallarini (2000), among others, and can be explained by the linear relation between dividends and consumption implied by the model. Similarly, the direct link between consumption growth rates and the risk free asset explains the overestimated correlation between the excess returns and the output growth rates: risk free movements are completely driven by the consumption path which determines the risk free and output co-movements as well. The benchmark model also reproduces the empirical autocorrelation of the risk-free rate.

Table 2: Model vs Data moments

Series	Model	Data
$\sigma(\Delta y)$	3.298	2.233
$\sigma(\Delta c)$	1.897	1.833
$\sigma(\Delta I)$	6.171	6.259
$\sigma(\Delta c)/\sigma(\Delta y)$	0.575	0.821
$\sigma(\Delta i)/\sigma(\Delta y)$	1.871	2.803
$\rho(\Delta c, \Delta y)$	0.324	0.658
$E[R^{ex}]$	5.908	5.998
$\sigma(R^{ex})$	6.017	16.319
$\rho(E[R^{ex}], \Delta c)$	0.508	0.000
$E[R^f]$	4.136	1.795
$\sigma(R^f)$	0.555	2.543
$ACF[R^{ex}]$	0.011	-0.029
$ACF[R^f]$	0.719	0.590

[18] An important assumption in some Macro-Finance contributions (e.g. Abel (1999), Lettau et al. (2008), Croce (2014)) is to model leverage assuming that dividends on equity are a power function of aggregate consumption. This is a straightforward way to reduce consumption volatility keeping the dividends risky enough to have a sizable equity premium. Consistent with this assumption, we adopt a leverage coefficient of 2 as in Croce (2014).

5.1 Impulse Responses

In this subsection we explain the impulse responses to productivity shocks (long-run and short-run), monetary policy shock, and financial shock under the benchmark calibration. To better understand the results in this section, we reconsider the well-known Euler equation $E_t[\mathcal{M}_{t+1}r_{t+1}] = 1$, which implies that $E_t[r_{t+1} - r_{f,t}] = -cov_t(\mathcal{M}_{t+1}, r_{t+1})$. This suggests that capital must offer a higher equity premium when the stochastic discount factor and its returns move in opposite directions.

Productivity shocks: In figures 1, 2, 3 and 4 we show the impulse response functions of both macro and financial variables in the presence of positive short-run and long-run shocks.

When a positive short-run shock to productivity materializes, the households and entrepreneurs find it optimal to increase consumption, see Figure 1 (solid line). This is further reflected in an increase in aggregate consumption and labor hours. Investment also rises at the same time. Increasing investment allows the entrepreneurs to temporarily increase the capital stock and increase output. These impulse responses are fully consistent with the results of any standard RBC model.

When a positive long-run shock to productivity materializes, the results differ, see Figure 3 (solid line). Since the long-run shocks are persistent, even a small shock can have a very strong effect on consumption and savings decisions of households. A long-run shock generates both an income effect and a substitution effect, which work in opposite directions. For households, a positive long-run productivity gives rise to a substitution effect which results in an increase in the opportunity cost of consumption. Thus, households decrease consumption and increase savings. The income effect causes the agent to feel wealthier and to desire an increase in consumption at the same time. The persistence of the shock affects the household's flow of expected future utility over a long period of time. This causes a dramatic increase in the continuation value for the agent. For a given output, the income effect tends to produce an increase in consumption and a drop in savings. However, when the IES is sufficiently high (as in the benchmark calibration) the degree of substitutability between continuation value and current consumption is also high.[19] Thus, the substitution effect dominates the income effect, and the households find it optimal to save more and consume less. Since there exists a complementarity between consumption and leisure, households find it optimal to reduce leisure and increase labor hours. Entrepreneurs tend to increase investment in the presence of a long-run shock and this also causes an increase in output. Entrepreneurs who exit the market consume their left-over capital stock. The aggregate consumption falls as household consumption is the major component of aggregate consumption.

Investment rises after both positive short-run and long-run shocks and this result is consistent with the empirical evidence. An increase in investment causes the price of capital to appreciate, so that under both types of shocks there are larger returns in the capital market along with a contemporaneous fall in the stochastic discount factor. Capital market returns are risky with respect to both sources of risks, and therefore the equity premium increases in both cases. The equity premium increases more under a short-run risk. The risk-free rate is persistent and rises in response to both sources of risk, however the rise is very small. This result is a success with respect to standard habit models (e.g. Jermann, 1998), which are known to produce an excessively volatile risk-free rate contrary to the observed data. The net worth of entrepreneurs increases under both types of productivity shocks, but is more persistent under the long-run shock as evident by the hump-shaped impulse response for net worth. The asset price gap is positive under a short-run productivity shock since the current price of capital rises due to a high investment demand. However, the gap turns negative during a long-run productivity shock since the price of capital continues to rise in the subsequent periods.

The external finance premium decreases as those are favorable productivity shocks.[20] Inflation decreases under both sources of risk since the central bank partly responds to the

[19] If the IES is low enough, current consumption and continuation value are complements: the income effect dominates, and the agent finds it optimal to increase consumption by reducing investment, in contrast to what is observed for high values of the IES, see Croce (2014).

[20] The graph of external finance is only an indicator of the external finance premium since it is measured as the ratio of the cost of borrowing externally to self-financing. This was measured in this manner for computational tractability.

improvement in productivity by changing the nominal rate. During a short-run productivity shock, the nominal rate increases in response to higher output causing inflation to fall. Also, under a long-run productivity shock, the nominal rate slightly increases and is responsible for a decline in inflation.

Financial Shocks:

Figures 5 and 6 depict the response of our endogenous variables to a a financial shock. We examine the effects of a financial shock which causes the cost of capital for enterpreneurs to fall, similar to what is observed during a stock market boom. Thus, in the event of a financial bubble, the market price of capital deviates from its fundamental price. Under the benchmark calibration, we observe a decrease in the asset price gap which causes stock returns and equity premium to go up. The external finance premium (the difference between the cost of funds raised externally and the opportunity cost of funds internal to the entrepreneurs) decreases as the net worth for entrepreneurs rises during a stock market boom.

The stock market boom creates a tradeoff between consumption and saving for households. Households decrease consumption and increase saving. A higher saving by households is a result of an increased demand for loans from entrepreneurs that translates into a higher real rate of return on loans. Households, who own retail firms, also benefit from a stock market boom through higher dividends. Entrepreneurs increase investment since price of capital is low and increase labor hours to produce more wholesale ouput. The increase in investment offsets the fall in aggregate consumption and results in an increase in output. The markup varies inversely with aggregate demand. Due to nominal price rigidity, the firms that keep prices fixed respond to an increase in demand by buying more wholesale goods from entrepreneurs. This causes a relative increase in the price of wholesale goods relative to final goods and bids down the markup. Thus, a fall in the markup increases inflation.[21]

Monetary Policy shocks:

[21] Inflation is high when firms expect average markups to be below their desired or steady state value. Thus, when firms reset prices, they choose prices above the economy's average level of prices to readjust the markup close to the desired level, see Galí (2008).

A contractionary monetary policy shock (figures 7 and 8) that causes the nominal rate (or policy rate) to increase results in a decline in the demand for capital and investment. This leads to a decline in the stock return and thus a decline in the equity premium. The decline in investment puts a downward pressure on the price of capital and net worth. Since a rise in the policy rate raises the opportunity cost of consumption, households respond by reducing consumption. Entrepreneurial consumption also falls although this is due to the decline in the price and demand for capital. Aggregate consumption decline and output falls. Labor hours also decrease in response to an increase in the policy rate, which is a standard result in the literature. With an increase in the policy rate there is a downward pressure on inflation.

6 Optimal Monetary Policy and Loss functions

The central bank is assumed to have a periodic loss function that is quadratic in inflation and output growth:

$$L = \lambda_1 \pi_t^2 + \lambda_2 y_t^2$$

Essentially, all of our monetary policy rules evaluate whether the addition of asset price bubbles to a simple feedback rule for the policy rate instrument, leads to a lower value of a suitable loss function as described above, where weights on inflation and output growth are given by λ_1 and λ_2. We then search over the parameters in the Taylor type rule specified in equation (14), to find the values of the feedback coefficients that minimize the loss functions as presented in Table 3.

Table 3: Optimal Simple rules

Description	λ_1	λ_2	ϕ_{pi}	ϕ_y	ϕ_f	Loss
Strict inflation targeting	1	0	1.46	0.27	0.73	4.45E-07
Targeting both inflation and output	1	1	1.16	1.19	0.49	0.000779

In our experiments we find that the coefficient on inflation is in line with the Taylor principle which suggests that the policy rate should adjust more than one for one in response to inflation. In addition, the optimal rule under the two loss functions suggest having some weight on the asset price gap (or financial instability) as opposed to absolutely no response. Whether the central bank chooses strict inflation targeting or targets both inflation and output, the feedback rule under optimal policy suggests responding to financial instability.

Cecchetti et al. (2000) have stressed the importance of distinguishing between the loss function, which defines the target variables, and the reaction function, which defines the response of the policy interest rate in terms of variables that need not themselves be target variables. For example, if asset prices were included in the reaction function, this did not necessarily imply that "asset price targeting" was taking place. Rather, it could reflect the fact that responding to asset prices helped in targeting other variables that entered the loss function.

Next, we compare the impulse response functions obtained under the optimal policy rule where the central bank cares equally about inflation and output to those obtained under the benchmark model.[22] These are again seen in Figures 1 - 8. While qualitatively our results remain the same under positive short-run and long-run productivity shocks, we find that the optimal policy rule decreases the volatility of both macro and financial variables. However, the tradeoff is that the central bank will be "smoothing" the policy rate under optimal policy less than the benchmark. We do not see stark differences between the impulse responses obtained under optimal policy vs. the benchmark monetary policy rule during a financial shock. However, under a contractionary monetary policy shock, all of the macro and financial variables show significant lower volatility under the optimal rule vs. the benchmark rule.

These results are interesting in suggesting that optimal monetary policy in economies where macro-financial inter-linkages are modeled can suggest reaction functions that are different that what we traditionally observe. Under the variety of shocks that we consider,

[22] Results are essentially the same when the optimal policy rule obtained from strict inflation targeting is used as a mean of comparison.

we find that responding to an asset price gap in addition to inflation and output can produce lower fluctuations in both macroeconomic and financial variables. These rules can better facilitate and support the "dual mandate" objective of the central bank more precisely.

7 Conclusion

Events in the last decade, such as the burst of the dotcom bubble in 2000 and thethe sub-prime mortgage crisis in 2007, have intensified the interest in exploring the role of monetary policy in ensuring financial stability. The aforementioned studies have argued that an exclusive focus of monetary policy on achieving price stability is inappropriate in a world where asset price misalignments and financial imbalances are increasingly rampant.

While the literature that supports a strict inflation-targeting approach dictates that central banks should adjust monetary policy actively and pre-emptively to offset inflationary or deflationary pressures, it also suggests that policy should not respond to changes in asset prices, except insofar as they signal changes in expected inflation. However, recent literature on macro-finance has expressed the need for understanding the way in which financial imbalances and asset price misalignments affect macroeconomic outcomes.

Our paper contributes to this theme by integrating macroeconomic and financial market inter-linkages to improve our understanding of the design of optimal monetary policies in the presence of different types of shocks. The main result of our paper is that optimal monetary policy should react to asset price misalignments and/or to financial imbalances over and above its impact on the inflation outlook. This result holds under the two standard objective functions of central banks (i.e. strict inflation targeting or inflation and output targeting). It should be noted that responding to asset price misalignments helps in effectively targeting variables like inflation and/or output that entered the central bank's objective function, consistent with its mandate(s). It is reasonable to assume that the debate on the response of monetary policy to financial imbalances will remain on the agenda for both monetary economists and central bankers for many years to come.

Figure 1: Short run productivity shock and macro variables

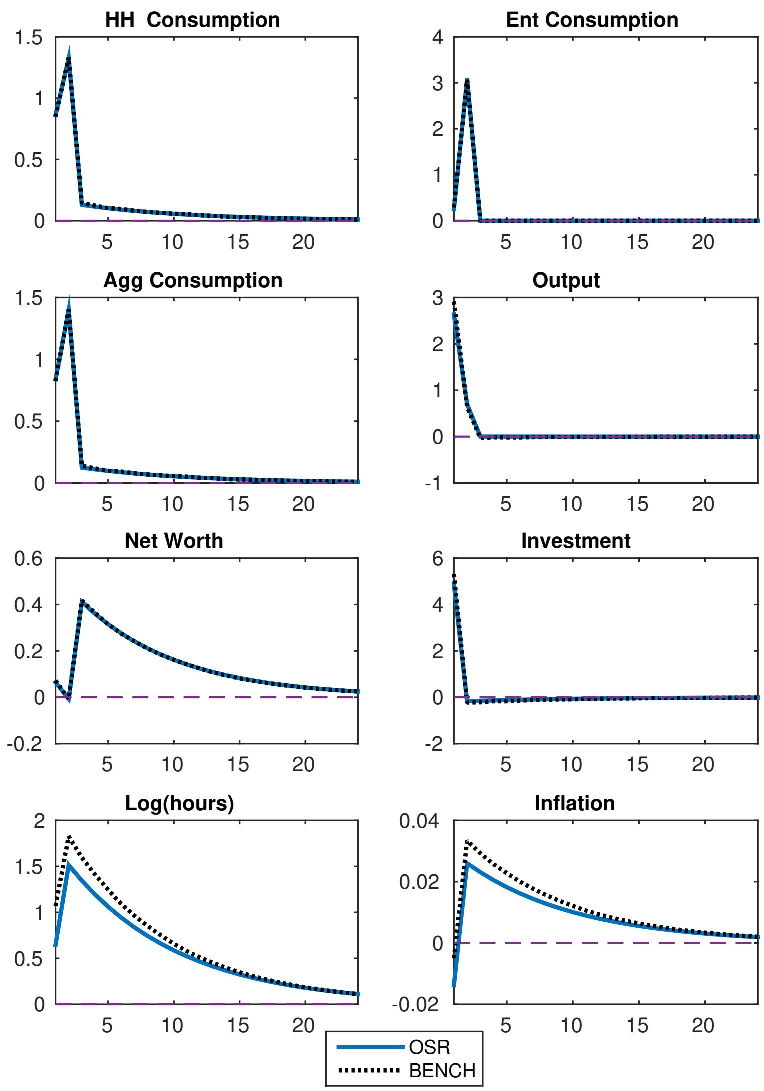


Figure 2: Short run productivity shock and financial variables

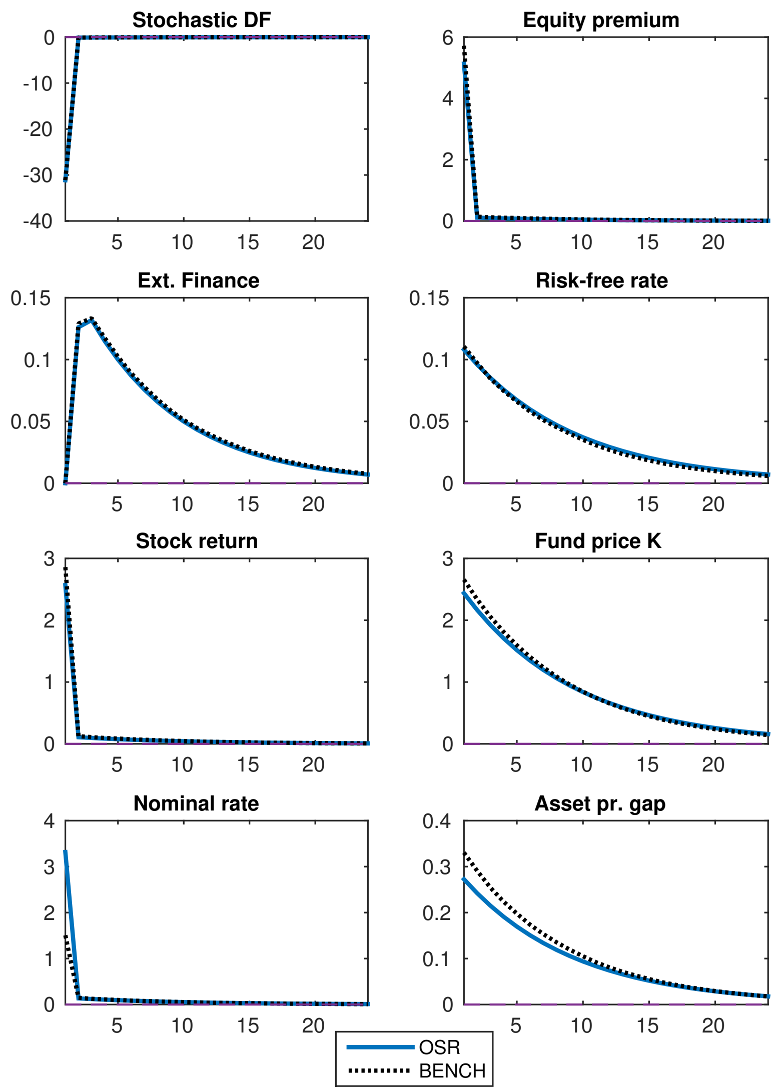


Figure 3: Long run productivity shock and macro variables

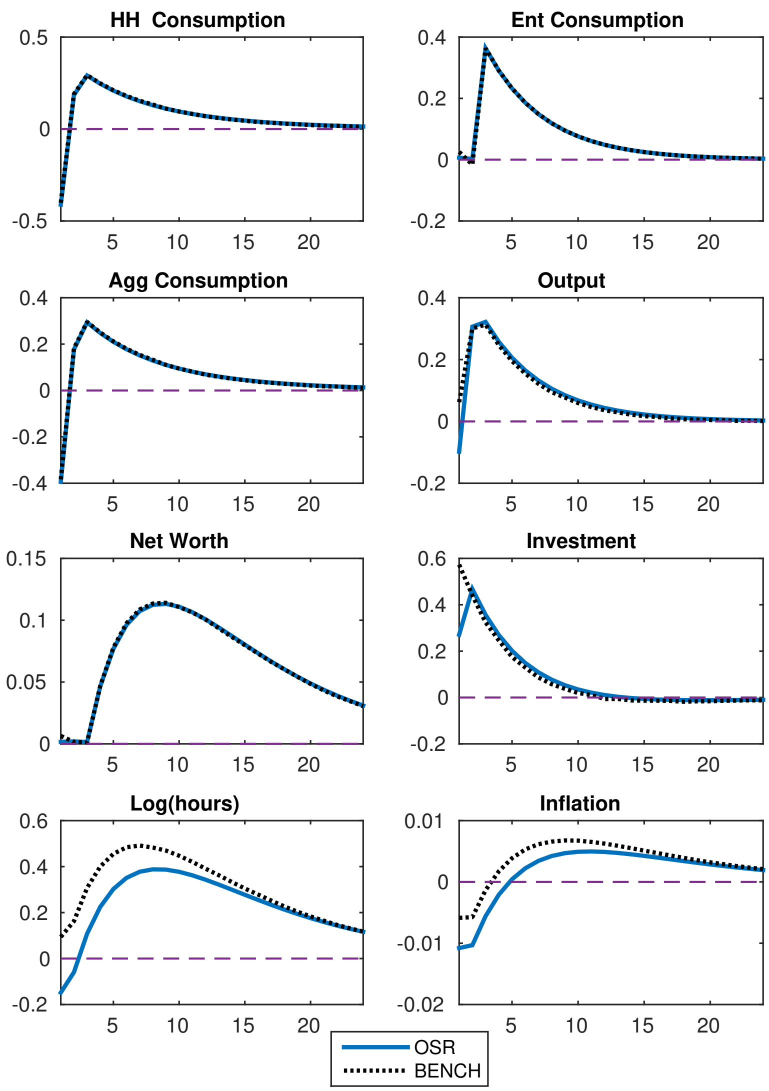


Figure 4: Long run productivity shock and financial variables

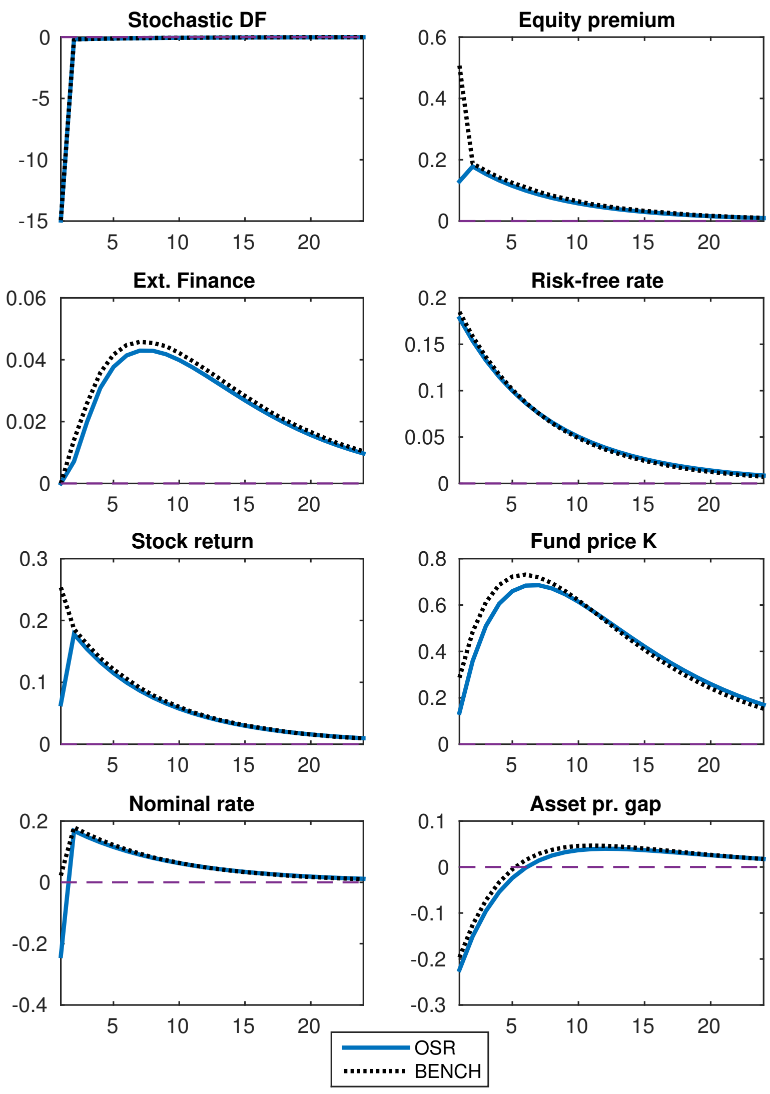


Figure 5: Financial shock and financial variables

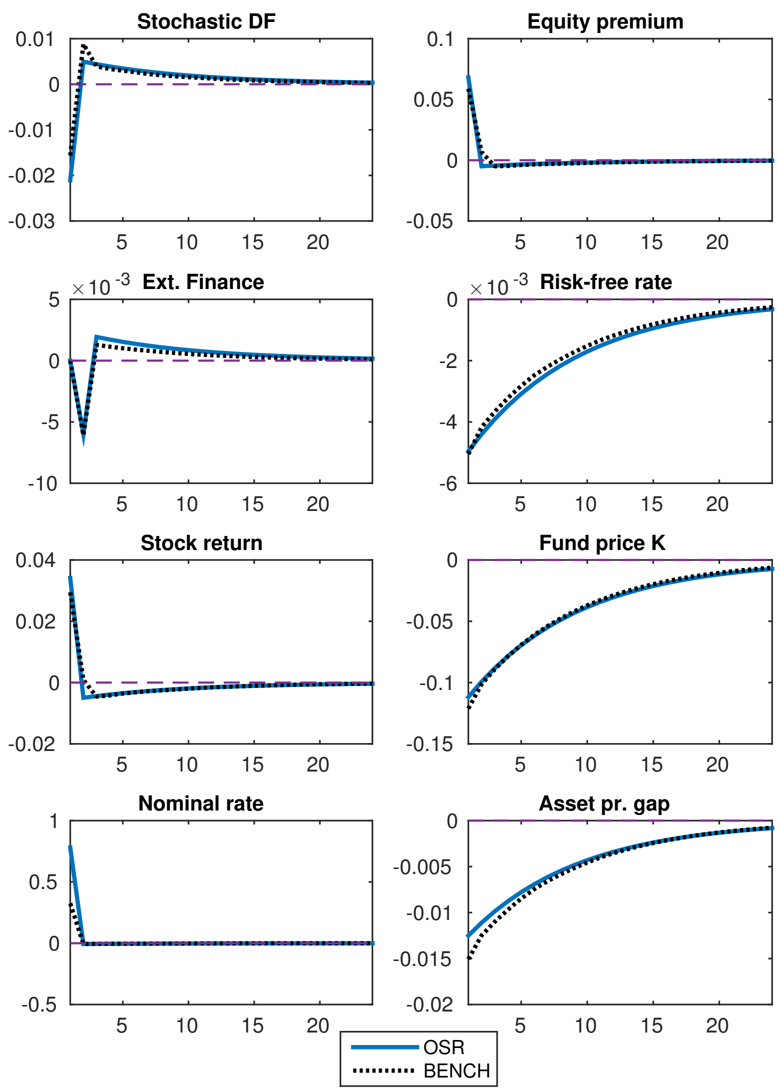


Figure 6: Financial shock and macro variables

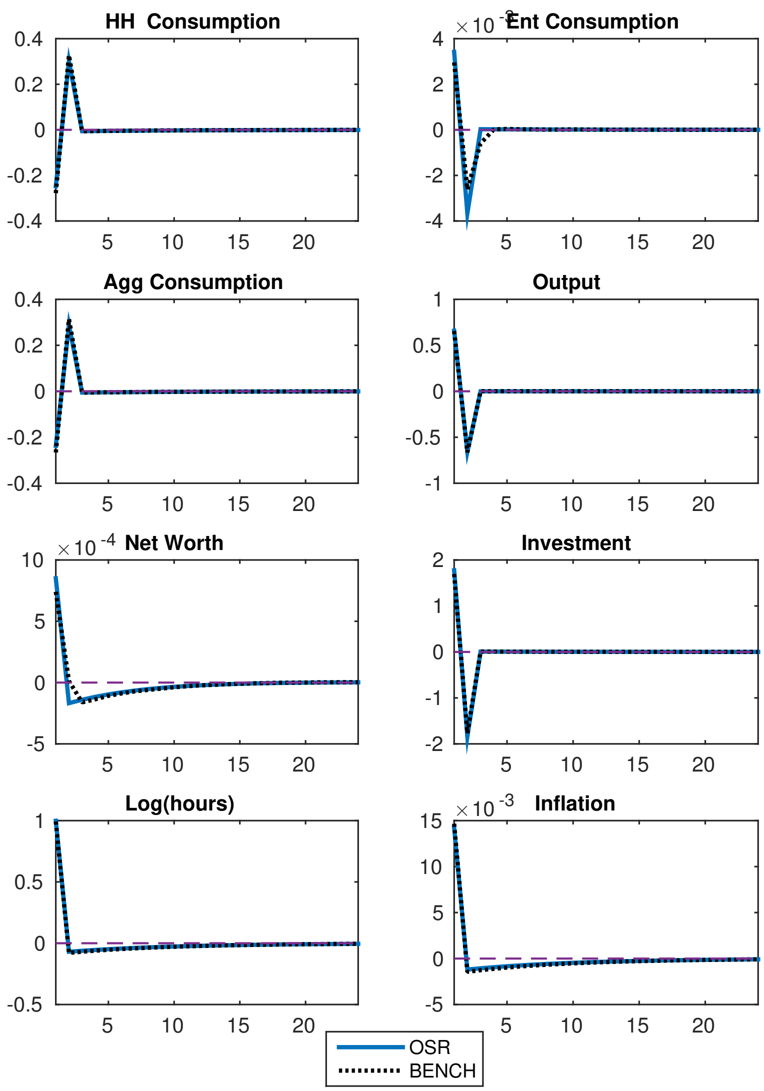


Figure 7: Monetary Policy shock and macro variables

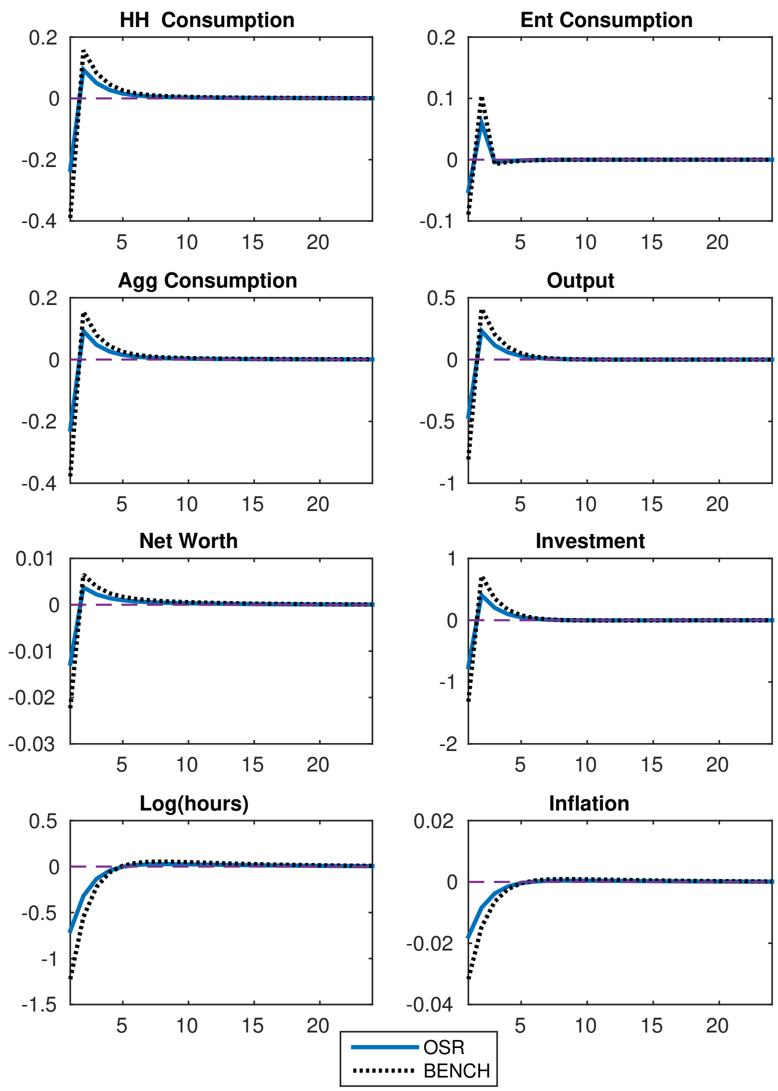
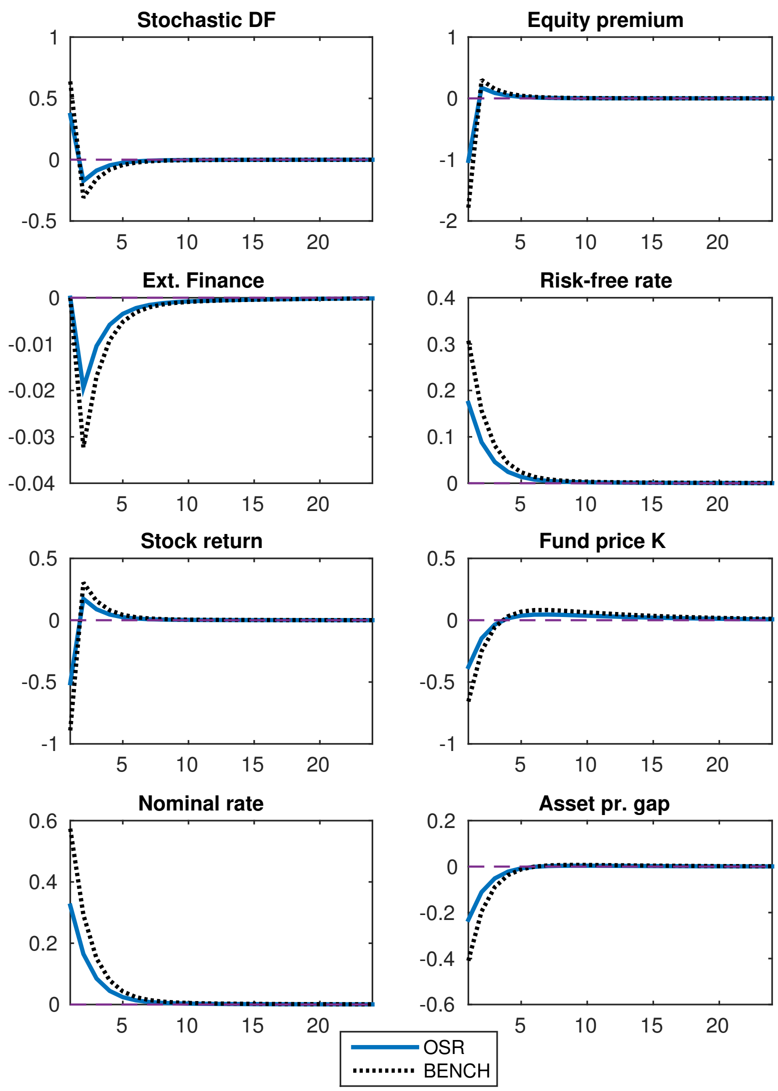


Figure 8: Monetary Policy shock and financial variables



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