Stabilizing Non-Fundamental Asset Price Movements under Discretion and Limited Information

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Abstract

Inflation, output and interest rate stabilization are all potential central bank objectives. We explore whether monetary policy should respond to asset price fluctuations, when they are driven by irrational expectational shocks to the future returns to capital. In our model, an optimistic shock to future returns generates both an increase in equity prices and physical investment. The increased investment is inefficient and, thus, a central bank optimally responds to this expectations shocks. This induces a trade-off between stabilizing nominal prices and non-fundamental asset price movements. We compare the optimal policy under different assumptions: full versus limited information and commitment versus discretion. If the central bank has limited information about whether an asset price movement has a fundamental or non-fundamental origin, then the central bank responds less aggressively to the non-fundamental exuberance shocks than under full information. Without commitment, a central bank responds more aggressively to non-fundamental exuberance shocks.

1 Introduction

This paper studies optimal monetary policy when agents sometimes have irrationally positive or negative expectations about the value of claims on the capital stock. These irrational expectations lead to both non-fundamental movements in asset prices as well as over or underinvestment in physical capital. Because of these real effects, a central bank has incentive to respond to these shocks. We also ask how limited information and lack of commitment each affect the optimal response to these expectations shocks.

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During the past decade, many developed economies have seen a tight connection between physical investment and the stock market. Figure 1 plots real quarterly fixed business investment and a broad measure of market capitalization in the U.S. and U.K. from 1990 to 2001. The asset price-run up of the mid and late 1990s coincided with a significant increase in the business investment over the same period. In each year between 1994-1999, investment relative to the capital stock grew at a rate at least 4 percentage points above its post-WWII average. This investment was associated with low unemployment and the longest boom in postwar history. Ex post, as well as ex ante to some observers, the stock market run-up fit into a classic asset price bubble scenario. Shiller (2000) reports that the S&P500 price-earnings ratio reached 44.3 by January 2000. Figure 1 shows the dramatic decline in share prices in 2000-01 occurred alongside a significant decline in physical investment. Throughout this period, nominal price inflation remained low and stable.

When stock prices began a sharp decline in the U.S. and U.K. in 2000, investment in equipment and structures also declined dramatically. One explanation for the rise in equity prices over this period is excessive optimism by stock holders, as described in Shiller (2000). Deviations from rationality have been used not only to explain asset price run-ups and subsequent declines, but also to understand the observed volatility of physical investment at business cycle frequencies. Keynes appeals to "animal spirits" changing the expectation of future returns to capital in order to explain fluctuations in physical investment. Investment volatility makes up a large component of the business cycle.

Adding to the macro evidence, the recent past has delivered many case studies of rapid stock-price appreciations followed by large purchases of equipment and structures. Consider the case of Webvan, founded in 1997 to deliver groceries ordered over the Internet as an alternative to traditional supermarket shopping. Soon after its $746 million initial public offering in 1999, the company had an $8 billion market capitalization. In keeping with its original business plan, Webvan signed a $1 billion contract to have facilities built in 26 cities as part of its expansion of operations. While some facilities were constructed, including an estimated $40 million Atlanta warehouse, and $40 million was invested in software development in 1999 and 2000, Webvan's subsequent 99% share price decline, NASDAQ delisting and bankruptcy forced the company to cease all operations.

Behavioral economics offers several potential explanations for non-fundamental movements in asset prices that are not available in neoclassical models. For example, Shiller explains how word-of-mouth communication regarding particular stocks may be more important than potentially more objective media coverage.

Figure 1 suggests that these two phenomena may be linked. A non-fundamental increase in stock prices can cause an increase in physical investment either through a Tobin's q effect or because the equity financed cost of capital falls. Alternatively, suppose equity market participants and firm managers irrationally overestimate the future returns to leasing capital. If capital is quasi-fixed because of investment adjustment costs, then the belief of higher returns to capital accumulation will spur investment and drive up equity prices. Blanchard, Summers and Rhee (1993) also identify a relationship between non-fundamental asset price movements and investment. They summarize their findings: "an increase of 1 percent in market valuation not matched by an increase in fundamentals leads to an increase in investment of 0.45%."

By comparison, in neoclassical models, rational asset price bubbles usually exist because the bubble asset performs a valuable service such as: risk sharing, intertemporal consumption smoothing or displacing dynamic inefficiency. This service arises because of missing markets. To understand non-fundamental asset price movements, the behavioral approach may be more appealing than the neoclassical approach. For example, it is more likely that investors bought high price stocks with hopes of keeping up with profits of successful investing neighbors rather than as a way to smooth consumption over time.

This paper studies a sticky price-imperfect competition model with capital accumulation and investment adjustment costs. Households and firms occasionally depart from rational expectations. Our model is 'reduced form' behavioral. These short-term deviations from rationality are assumed rather than modeled. In this sense, the strategy follows Cecchetti, Lam and Mark (2002), who also assume but do not model, deviations from rationality in order to explain certain asset pricing anomalies.

Dupor (2002) studies how a central bank with full information and commitment, which we refer to as case (a), responds to shocks to expectations. In this environment, he establishes that a central bank optimally responds to both nominal price and non-fundamental asset price fluctuations. Each measures a distinct distortion on the economy. Why is this true?

First, consider nominal price inflation. Because sticky price firms do not change prices quickly, each must meet demand at the posted price by hiring or firing workers. If they are selling too many goods, firms begin increasing their price to return to their desired employment level. This creates nominal price inflation and indicates that labor is being overused relative to the optimum. In terms of efficiency, nominal price inflation indicates a distortion on the consumption-leisure margin.

Next, consider asset price inflation. When firms receive positive expectations shocks, they become overly optimistic and increase physical investment. In this model, a sufficient statistic for investment is marginal q. Given our form of adjustment costs (as in Hayashi 1982), marginal q equals average q. Average q can be read off observed equity prices. In terms of efficiency, non-fundamental asset price inflation indicates a distortion on the consumption-investment margin.

Public finance instructs that a benevolent government uses its instruments to minimize the distortions; therefore, a central bank should be concerned with both nominal and asset prices because it cares about both of the above margins. Thus, the optimal rule responds to both nominal and asset price movements. In addition, since the central bank has only one instrument, there is a trade-off between nominal price and asset price stabilization.

This paper considers the distinct and combined effects on the optimal policy response to exuberance shocks of: (b) limited information and (c) lack of commitment. With limited information (b), the central bank is uncertain whether true productivity growth or irrational expectations drive observed higher current asset prices. This reduces the central bank's willingness to tighten policy initially. The expectations shock drives up investment demand. Without contracting monetary policy, the main impact is that employment rises initially relative to the full information case. With discretion (c), the central bank cannot commit to raise long-term real rates because this policy is not time consistent. Instead, it combats irrational exuberance towards investment by reducing current employment in each period for a significant number of periods. This slows the rate of investment by directly reducing output in each period.

The next section presents a sticky price model with investment adjustment costs. The model has two shocks: productivity and 'exuberance' shocks. A central bank that cannot observe the exuberance shocks directly must solve a filtering problem. In section 3, we study optimal monetary policy under three assumptions: (a) full information under commitment, (b) limited information under commitment, (c) full information under discretion. Section 4 considers two extensions: positively correlated expectations and technology shocks as well as combining limited information and discretion. Section 5 concludes.

2 A Sticky Price Model with Irrational Investment

The model consists of three types of participants: a continuum of household-firms, a continuum of investment good firms and a single central bank.

Household-Firm Problem

A representative household-firms maximizes

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma} c_t^{1-\sigma} - A n_t - \frac{\gamma}{2} \left(\frac{P_t}{P_{t-1}} - 1 \right)^2 + v_t \right] \tag{1}$$

subject to

$$\frac{M_t}{\bar{P}_t} + h_t \leq \frac{P_t}{\bar{P}_t} y_t + (1+s)\, w_t n_t - w_t \tilde{n}_t - \frac{r_t}{1+s} k_t - c_t + z_t + \frac{M_{t-1}}{\bar{P}_t} \tag{2}$$

for all $t \geq 0$, where $A, \gamma, \sigma > 0$. M_{-1} is given as an initial condition. Here c_t denotes consumption, w_t the real wage, r_t the rental price of capital, M_t money holdings and z_t profits of investment goods firms. Also, $\bar{P}_t$ denotes the aggregate nominal price index. We require $c_t, M_t, n_t, \tilde{n}_t \geq 0$.

Household-firms hire $\tilde{n}_t$ labor units from the labor market for own production and supply n_t own labor units to the labor market. Next, we assume subsidies to labor supply and capital rental, which are financed through lump sum taxes h_t. The magnitudes of the subsidies do not vary over time and are determined by s.

Household-firms face a quadratic utility cost of changing own prices and, thus, dislike changing their own nominal price P_t rapidly. At the same time, household-firms also derive disutility, $G < 0$, or potentially positive utility, $G > 0$, from changes in the average price level:

$$v_t = \frac{G}{2} \left(\frac{\bar{P}_t}{\bar{P}_{t-1}} - 1 \right)^2$$

Note that v_t is external to the firm and does not affect first-order conditions.

We introduce v_t to make possible a realistic model calibration. The internal cost of price changes, determined by γ, allows us to match empirical estimates of the forward-looking expectational Phillips curve; the external costs, determined by G, together with the internal costs allows us to match empirical estimates of the direct 'menu costs' of nominal price rigidity.

Household-firms have a perfectly inelastic demand for real balances, which is omitted from (1) for simplicity. This will determine the price level in equilibrium. The assumption allows us to abstract from the distortion due to households economizing on cash balances.

Household-firms must meet demand given the price they charge P_t:

$$y_t = Y_t^d D \left(\frac{P_t}{\bar{P}_t} \right) \tag{3}$$

where Y_t^d denotes economy-wide total demand for goods. Let $D(1) = 1$ and $D'(1) \equiv \phi < -1$. The household-firm production function is:

$$y_t = a_t k_t^{\alpha} \tilde{n}_t^{1-\alpha} \tag{4}$$

where a_t is total factor productivity.

Imposing the household-firm optimality conditions, along with symmetry and market clearing, we have:

$$\gamma(\pi_t - 1)\pi_t - \beta\gamma E_t[(\pi_{t+1} - 1)\pi_{t+1}] = (1+\phi)(c_t)^{-\sigma} a_t k_t^{\alpha} n_t^{1-\alpha} - \left[\frac{\phi A}{(1-\alpha)(1+s)}\right] n_t \tag{5}$$

$$r_t = \frac{\alpha A}{(1-\alpha)}\left(\frac{n_t}{k_t}\right)(c_t)^{\sigma} \tag{6}$$

where $\pi_t \equiv P_t/P_{t-1}$. Optimal price setting requires that (5) holds. Cost-minimization implies (6).

The government subsidizes labor and capital to generate steady-state efficiency: $1 + s = \phi/(1+\phi)$.[1] Then, (5) becomes

$$\gamma(\pi_t - 1)\pi_t - \beta\gamma E_t[(\pi_{t+1} - 1)\pi_{t+1}] = \frac{(1+\phi) n_t}{1-\alpha}\left[(1-\alpha) a_t \left(\frac{k_t}{n_t}\right)^{\alpha}(c_t)^{-\sigma} - A\right] \tag{7}$$

Intuitively, firms would like to set marginal revenue equal to marginal cost in each period (which equals their price due to the subsidy); however, costs of adjusting prices imply that prices are changed slowly in response to shocks.

Note that the efficient allocation between leisure and consumption, given the current capital stock, occurs if:

$$(1-\alpha) a_t \left(\frac{k_t}{n_t}\right)^{\alpha}(c_t)^{-\sigma} - A = 0 \tag{8}$$

which states that the marginal utility of consumption generated by additional work should just offset the disutility of that work. This is exactly the bracketed term on the right-hand side of (7). Equation (8) has two important implications. First, current inflation is a summary statistic for the expected future consumption-leisure distortion. Solving (7) forward, π_t is a labor weighted sum of the marginal misallocation of labor. Second, it implies that in order to generate efficiency on this margin, a central bank should stabilize the price level $\pi_t = 1$. Inflation measures the extent of current and expected future distortion on the consumption-leisure margin.

Investment Firm Problem

Investment firms determine the level of capital accumulation. They do not issue new shares or bonds and are owned by households-firms. The firm's one-period real profit is:

$$z_t = r_t k_t + (1-\delta) k_t - k_{t+1} - \Phi\left(\frac{k_{t+1}}{k_t}\right) k_t$$

[1]This assumption is commonplace, e.g. Rotemberg and Woodford (1997), and useful in abstracting away from well-understood time consistecy issues that give rise to a steady-state inflation bias. It allows us to narrrow our focus on the new time consistency problem introduced by expectation shocks.

where Φ is a nonnegative, convex adjustment cost function. At time t, the firm's perceived future profits are:

$$\tilde{z}_{t+j} = R_{t+j}k_{t+j} + (1-\delta)\,k_{t+j} - k_{t+j+1} - \Phi\left(\frac{k_{t+j+1}}{k_{t+j}}\right)k_{t+j} \text{ for } j > 0$$

where

$$R_{t+j} \equiv \alpha\theta_{t+j}a_{t+j}\left(\frac{k_{t+j}}{n_{t+j}}\right)^{\alpha-1} \tag{9}$$

Note that R_{t+j} equals the marginal product of capital in period $t+j$ multiplied by the distortion θ_{t+j}.[2] In the rational expectations case case, $\theta_t = 1$ for all t. Firms invest inefficiently if $\theta_{t+j} \neq 1$. This assumption reflects our desire to understand how optimal policy should respond to *distortionary* shocks to an economy-wide investment schedule. One interpretation of θ_t is that non-fundamental and large movements in asset prices move physical investment through a q effect.

The firm rents k_t to household-firms in the current period, conducts physical investment out of retained earnings and seeks to maximize:

$$\eta_t z_t + E_t\sum_{j=1}^{\infty}\left[\beta^j\eta_{t+j}\tilde{z}_{t+j}\right] \tag{10}$$

where θ_t is a stochastic process and η_t is the marginal utility of household consumption at time t.

Substituting out (6), the firm's investment decision satisfies:

$$1 + \Phi'(g_{t+1}) = \beta E_t\left[\left(\frac{c_t}{c_{t+1}}\right)^{\sigma}\left(R_{t+1} + 1 - \delta - \Phi(g_{t+2}) + \Phi'(g_{t+2})\,g_{t+2}\right)\right] \tag{11}$$

where $g_{t+1} \equiv k_{t+1}/k_t$.

We have three equations (4), (7) and (11) in four unknown endogenous processes $\{c_t, k_t, n_t, \pi_t\}$. Other than the exogenous disturbances, the fourth equation is the policy rule. We construct several rules in section 3.

The Stock Market

An investment firm's worth is the value of its installed capital. In a typical investment model (e.g. Hayashi 1982), the firm's equity market value equals marginal q. Furthermore, the adjustment cost function Φ implies the equality of marginal and average q. Our model is atypical because of the expectation shock.

[2]The model profit function $\tilde{z}_t$ also assumes capital gets paid its marginal product. This is only exactly true when the central bank stabilizes the nominal price level.

To calculate the price of equity below, we assume that household-firms share the investment firms' expectations regarding future profits, including θ. This is a good assumption if household-firms do not believe that they have better information on future aggregate dividends than investment firms. On the other hand, the household-firm has rational expectations about the future cost of capital—which is necessary to construct a forward-looking pricing policy. This is an appropriate if household-firms are knowledgeable about the particular capital input used in own production, but are not knowledgeable about the entire economy's capital good producing firms.

Exogenous Disturbances

The model has two types of disturbances: productivity and expectation shocks. We state their laws of motions for these shocks in percentage deviations. Let $\hat{x}_t \equiv \log(x_t/\bar{x})$. Assume

$$\hat{a}_t = \underline{\hat{a}}_t + \omega \hat{a}_{1,t} + (\omega - 1)\,\hat{a}_{2,t} \text{ and } \hat{\theta}_t = \omega \hat{\theta}_{1,t} + (\omega - 1)\,\hat{\theta}_{2,t}$$

$$\hat{a}_{j,t+1} = \rho_j \hat{a}_{j,t} + \hat{\varepsilon}_t^a \text{ and } \hat{\theta}_{j,t+1} = \rho_j \hat{\theta}_{j,t} + \hat{\varepsilon}_t^\theta$$

for $j = 1, 2$. Let $\hat{\varepsilon}_t^a, \hat{\varepsilon}_t^\theta, \underline{\hat{a}}_t$ be mean zero, uncorrelated white noise shocks with potentially different variances. How are the three shocks chosen: the non-fundamental expectations shock as well as the iid and persistent productivity shocks?

The expectations shock is based on U.S. data. First, we compute a measure of the cyclical component of aggregate equity price fluctuations in the late 1990s and early 2000s. To compute it, take the log of the per capita annual total return on the S&P500 (dividends reinvested) from 1970 to 2002 and remove a linear trend. There is a gradual run up followed by a rapid decline beginning in 1999-2000. Next, we calibrate the θ impulse response (figure 2(d)) to best match the dotted line.

The relative shock volatilities reflect the idea that 'bubbles' occur infrequently. For example, Shiller (2000) identifies five major stock run ups since 1920. Thus, expectations shocks likely play a small role, relative to other shocks, in explaining cycles. In our model, productivity shocks mainly drive fluctuations. This will bias our results– under limited information–towards finding a smaller policy response to equity prices

The two productivity shocks combined are chosen to explain 100% of post-war U.S. output volatility. Next, productivity consists of its persistent and iid components. A central bank with limited information works to parse expectations shocks, which it should respond to, from persistent productivity shocks, which it shouldn't respond to. IID TFP shocks act as 'noise' that make uncovering the persistent TFP shock more difficult. To make the signal-to-noise ratio small, the iid component of TFP Column (i), by itself, is set to explain 85% of post-war U.S. output volatility. Specifically, $\sigma_{\underline{a}} = 2.04$.

Finally, the persistent TFP impulse response takes the same shape as the expectations shock. This additionally obfuscates the central bank's decision. The case when all three shocks are included is called the limited information under commitment (LIC) case. Summary statistics are in column (iii). This is our benchmark specification.

Firms form expectations regarding $a_{1,t}$ and $a_{2,t}$ rationally and observe each variable separately. They also observe θ_t and treat it as a real disturbance. This is the source of irrationality.

3 Optimal Monetary Policy

There are two possible information assumptions for the central bank. First, we assume the central bank has rational expectations regarding all variables and observes k_{t+1} and every time t variable at time t. Under this *full information* case, the central bank can perfectly distinguish non-fundamental from fundamental asset price movements. Under the second informational assumption, the central bank has *limited information*. The central bank's time t information set is $\{c_t, n_t, a_t, k_{t+1}\}$ and its lags. It does not observe $\theta_t, \underline{a}_t, a_{1t}$ or a_{2t}. The iid shocks to productivity will inhibit the central bank from inferring the fundamental value of stock prices from current productivity. However, even with limited information, the central bank knows the stochastic process for θ_t and also knows that these shocks are distortionary.

In addition to different informational assumptions, we consider both commitment and discretion. First, under limited information and commitment, the central bank maximizes

$$\tilde{E}_0 \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\sigma} (c_t)^{1-\sigma} - An_t + \lambda_t \left[a_t k_t^{\alpha} n_t^{1-\alpha} + (1-\delta) k_t - c_t - \Phi(g_{t+1}) k_t - k_{t+1} \right] \tag{12}$$

subjectto

$$\beta E_t \left(\frac{c_t}{c_{t+1}} \right)^{\sigma} \left(R_{t+1} + 1 - \delta - \Phi(g_{t+2}) + \Phi'(g_{t+2}) g_{t+2} \right) = 1 + \Phi'(g_{t+1})$$

where $g_{t+1} = k_{t+1}/k_t$. We have substituted out prices using current and future quantities in the incentive compatibility constraint. Also, it may be surprising that π_t does not appear in the central bank's problem. Because $\gamma = G$, the internal and external effects of prices changes of menu costs exactly offset. This allows us to focus exclusively on how monetary policy distorts the economy's real margins. Furthermore, we can ignore constraint (7) and π_t in (12) because they appear in no other constraints or the objective function.

The expectation operator used by the central bank $\tilde{E}[\cdot]$ differs from that of households $E[\cdot]$. The private sector has more information about the state of the economy than the central bank. The private sector's information set includes $\{a_{1t}, a_{2t}, \theta_t\}$, which is not available to the central bank. On the other hand, the central bank knows that there exist deviations from rationality through θ_t, as in the preceding model. In the full information case, the problem is identical to (12) except that $\tilde{E}[\cdot]$ is replaced with $E[\cdot]$.

The second dimension that we study concerns whether the central bank operates with commitment or under discretion. As a first step in solving the model, we take a second-order log-linear approximation to the objective function and a first-order approximation to the two constraints.

Solving for equilibria under limited information with or without commitment is more complicated. Although the model is linear-quadratic, there is asymmetric information between the central bank and private agents. This asymmetry breaks the separation principle—which normally allows one to solve the government's optimal policy and filtering problem each independently. Techniques developed in Svensson and Woodford (2002) are applied to solve the limited information models.[3]

For each commitment and information assumption, we express solutions to the central bank problem using steady-state impulse response functions. Under commitment, the reported impulse responses are computed as if the shock just occurred yet the commitment to the policy rule was made long ago. Woodford refers to this as optimal policy from a 'timeless perspective.' The nature of these experiments makes comparing welfare across different information and commitment assumptions difficult simply by looking at the impulse responses.

Calibration

We calibrate using parameters to match annual data. All parameters are identical across simulations. Only the nature of monetary policy varies. The parameters $\sigma, \beta, \alpha, \delta$ are in the standard range estimated in real business cycle models. Note that A measures the linear disutility of supplying labor. It is a scaling parameter set equal to 1. The parameter ϕ indexes the degree of monopoly power held by each household-firm. We set $\phi = -6$, which implies a steady-state markup equal to 20% in a zero inflation steady state.

We select $\Phi(1) = \Phi'(1) = 0$, which implies that average and marginal investment adjustment costs are zero at the steady-state. The curvature of the investment adjustment cost function, using the estimate from Hall (2002), is $\Phi''(1) = 1$. This value implies an elasticity of i/k with respect to

[3]These methods are also described in Dotsey and Hornstein (2002).

q equal to 11.1.

[**Table 1 goes about here**]

The parameters ρ_1, ρ_2, ω govern the stochastic processes for both the persistent component of productivity and the 'irrational' expectations process θ_t. These parameters are chosen so that a positive innovation, either to $\hat{\varepsilon}_t^a$ or $\hat{\varepsilon}_t^\theta$, has no initial period impact followed by an inverted hump shaped response. The innovation has its maximum impact in year ten following the innovation. After this, it decays monotonically. The impulse response of $\hat{\theta}_t$ to a one-standard deviation innovation in $\hat{\varepsilon}_t^\theta$ appears in panel D of figure 2.

[**Figure 2 goes about here**]

As explained above, we set $\gamma = G$ to remove the direct, or menu costs, of inflation on welfare. Instead, inflation and price stickiness will have negative welfare implications only to the extent that they distort real margins in the economy. Apart from being a useful theoretical distinction, Dupor (2002) calibrates these costs, $\gamma - G$, using estimates of central bank welfare functions. These estimates, not surprisingly, find that the direct costs are relatively small (e.g. Soderlind 2001).

[**Table 2 goes about here**]

The calibrated shock volatilities appear in Table 1 and column III of Table 2. Columns I and II help show the relative contribution of each of the three shocks. The shock variances are chosen to match roughly a subset of second moments from post-WWII U.S. data at business cycle frequencies. However, in three ways we departed from the standard RBC calibration. Each departure was chosen to make the job of a limited information central bank more difficult. First, assuming part of productivity movements are iid adds noise to the central bank's information, which makes it hard to infer the fundamental value of asset prices from observed a_t. With mostly iid productivity shocks, consumption is not as volatile in column III as in the data.

Second, we select a relatively high value of $\sigma_{\underline{a}}$, the standard deviation of the iid productivity innovation. This shock delivers 85% of the volatility of output. This implies a very low signal-to-noise ratio for the central bank with limited information. Third, we choose $\sigma_{\varepsilon\theta}$ to imply that expectation shocks only contribute a small fraction to the overall volatility of asset prices. Choosing a larger value would help generate greater investment and q volatility, two dimensions along which III does not match the data. Increasing $\sigma_{\varepsilon\theta}$ would make the central bank's filtering problem easier by raising the signal-to-noise ratio. Finally, the optimal policy under limited information and commitment is used to generate the business cycle second moments. Both the actual and model data are detrended with an HP filter setting the smoothing parameter equal to 400.

3.1 Assessing the Effects of Discretion and Limited Information

This section describes the dynamic responses of the model under three different central bank assumptions: full information under commitment, limited information under commitment and full information under discretion. The expectations and persistent productivity shocks are discusssed in turn.

Expectations Shocks

Consider a one standard deviation positive innovation to the expectation process θ_t. T At time zero, firms come to believe that, although the returns to leasing capital do not change in the current year, there will be an eventual rise in returns. These expectations are irrational. There will be no real change in returns to capital in the future; however, these boundedly rational firms increase investment in response to the shock. This creates a distortion in the economy.

The optimal policy with full information and commitment (hereafter, FIC) is represented by the solid line. FIC responds by allowing investment to increase somewhat, as seen in panel A. However, the central bank tightens monetary policy and thus does not allow employment to increase, as seen in panel C. Monetary policy under FIC is implemented by the central bank raising the short term real rate above its steady-state level (as shown in figure 3(b)).

[**Figure 3 goes about here**]

Since output is relatively unchanged (because the capital stock does not change quickly and labor changes very little under FIC), most of the investment increase results from a decline in current consumption. This is the solid line in figure 2(b). The central bank trades off the relative welfare costs of two distortions: distorting the consumption-investment margin, which is driven by the expectations shock, versus distorting the consumption-leisure margin. Increasing the real interest rate, that is the marginal rate of substitution, is one method to discourage current investment. By generating a steeply upward sloping consumption profile, consumption smoothing households are less willing to forgo current consumption to create investment goods.

The central bank's methods to offset a positive expectations shock are seen by examining the log-linearized equilibrium condition for investment:

$$\hat{k}_{t+1}-\hat{k}_t = \frac{1}{\Phi''(1)} E_t \left(\sum_{j=0}^{\infty} \beta^j \left[\beta r^* \left(\hat{\theta}_{t+j+1} + \hat{a}_{t+j+1} + (\alpha - 1) \left(\hat{k}_{t+j+1} - \hat{n}_{t+j+1} \right) \right) - \sigma \left(\hat{c}_{t+j+1} - \hat{c}_{t+j} \right) \right] \right) \quad (13)$$

Either increasing the real interest rate in the future, i.e. the consumption growth term, or decreasing the future actual rental rates of capital, $\hat{a}_{t+j+1} + (\alpha - 1) \left(\hat{k}_{t+j+1} - \hat{n}_{t+j+1} \right)$, works to offset the increase in $\hat{k}_{t+1}$ generated by a positive expectations shock. By keeping labor relatively constant into the future, the central bank decreases the future rental price of capital. This also discourages capital accumulation.

Consider the limited information with commitment (hereafter, LIC) policy response to the identical shock. These impulses are plotted as the diamond-marked line in the same figure. Since the central bank does not observe θ_t and only observes the sum of the components of productivity, it cannot know with certainty that a distortionary expectations shock has occurred.

Our choice of processes for θ_t and the persistent component of a_t gives the limited information model the best opportunity to reduce the response to asset prices relative to the optimum under commitment. Why? Consider the period of impact of the innovation to θ_t. There only a small change in initial period total factor productivity, however, asset prices and investment rise. From the central bank's perspective, this could be due either to excessive optimism or a persistent productivity shock. Also, the idiosyncratic component of productivity, $\underline{a}_t$, hides whether persistent productivity or irrational expectations is driving movements in asset prices and investment. Under a more standard AR(1) productivity process, whether or not current actual productivity changed would provide much more information as to which shock drove the movement in investment.

Panel C is instructive in understanding the response of employment under LIC. If the central bank is uncertain as to whether expected future a_t or θ_t growth is driving increased investment demand, it partially responds as if a persistent productivity shock is occurring. This response is complicated. First, the optimal response to a productivity shock involves intertemporal labor smoothing, which occurs under LIC. Consumption fall under LIC, as under FIC, because investment crowds out consumption; however, there is greater output under LIC because of higher employment. Second, investment is initially greater under LIC on the possibility that a persistent technology boom is under way. Eventually, the LIC central bank infers that an expectations shock has occurred and the LIC paths asymptote to the FIC paths for both consumption and investment. Note that LIC employment overshoots, instead of asymptoting to, FIC employment. Why does this occur? Since the capital stock is higher with LIC than FIC by the eighth year, the FIC central bank decides to run down the capital stock by reducing employment.

How does discretion change policy under full information? Compare labor in panel 2(c) under FIC (solid line) and FID (dashed line). Whereas employment is roughly constant under commitment, it falls dramatically under discretion. The FIC central bank offsets the θ increase by committing to a high real interest rate in the near and short-term. This reduces the amount of inefficient investment. The FID central bank, however, would not keep a promise to raise future interest rates. This is because after the θ shock begins dissipating, future central banks would no longer be willing to distort the economy with a high real interest rate. Instead, the FID central bank slows economic activity by reducing labor input in the immediate periods following the shock. Accordingly, figure 3(b) shows that the real rate changes less under discretion than commitment.

Figure 3 also plots impulse responses for Tobin's q, the one-year real rate as well as the real term structure immediately after and eight years following the shock. The initial response of q is slightly larger under limited information in the initial periods. Since the central bank with limited information believes that the asset price increase may be due to a burgeoning, persistent productivity increase, it accommodates the asset price movement to a greater extent. It is interesting to note that quantitatively the amount by which q is allowed to change between LIC and FIC is fairly close, even in the first few years of the shock.

Persistent Productivity Shocks

Consider a one-standard deviation shock to the innovation to the persistent component of productivity $\hat{\varepsilon}_t^a$. The impulse response of productivity, a_t, appears in panel D of figure 4. It is hump shaped and identical to the expectations shock.

Under FIC, there is both a wealth and substitution effect on labor supply. Increased wealth leads to lower employment in every period and employment is lowest when productivity is lowest (in the first few years). Consumption initially rises because of increased wealth. This implies that investment must fall initially because productivity has not changed, labor has fallen while consumption has increased. Eventually, there is an investment boom once a_t increases.

[Figure 4 goes about here]

To understand the difference between FIC and LIC, examine the labor impulse responses in panel C. Employment under LIC in the period of the shock is higher than under FIC. With limited information, the central bank in uncertain that productivity will actually be higher in the future. If future productivity does not increase, the central bank should not substitute away from current labor. The initial hump shaped pattern of labor under LIC in response to the productivity shock is similar to response of labor under LIC to the expectations shock. Eventually, the central bank learns that there has been a true productivity increase. Over time, the LIC labor impulse response approaches the FIC labor impulse response. The behavior of investment (panel A) and consumption (panel B) under LIC is similar to FIC, but shifted up. Larger initial employment under limited information leads to greater output, which is split between consumption and investment. As with labor, both consumption and investment asymptote to the full information case as time goes on.

The impulse response to each variable in figure 4 is identical across FIC and FID. The steady-state of this model is efficient and the productivity shock is not distortionary. There is no time consistency problem in response to a perfectly observed technology increase. In fact, the optimal response under both FIC and FID is to stabilize the nominal price level. This ensure that there is no consumption-leisure distortion. Furthermore, there is no consumption-investment distortion resulting from the productivity shock.

Figure 4 provides a response to one objection to the argument that a central bank should respond to asset prices changes. The argument goes: if the central bank chooses to respond to non-fundamental asset price movements, it sometimes mistakenly tightens when real productivity changes. In this case, limited information leads to a larger response of consumption and investment relative to the perfect information case. Optimal monetary policy which responds to asset prices, even under limited information, can amplify a boom driven by fundamentals. We do not plot the impulse response of prices in response to the productivity shock. They are straightforward to infer from the previous figure.

4 Two Extensions

4.1 Positively Correlated Expectations and Productivity Shocks

Many researchers have argued that dramatic asset price appreciation are sometimes associated with the arrival of new technology (e.g. Greenwood and Jovanovic 1999). Furthermore, because the technology has yet to be implemented on a wide-scale, individuals are uncertain as to whether the new idea will actually pay the enormous potential dividends in the future for investments made today. This view is taken by Peter Garber, in his book *Famous First Bubbles*, studies several episodes that are commonly described as bubbles.

> "These events were a vast macroeconomic and financial experiment, imposed on a scale that did not occur again until the war economies of this century. True, the experiment failed. Nonetheless, investors had to take positions on its potential success. It is curious that students of finance and economists alike have accepted the failure of the experiments as proof that the investors were foolishly and irrationally wrong (p. 125)"

In this subsection, we consider the possibility that technological advance, a_t and excessive optimism, θ_t, are positively correlated. In the previous sections, productivity and expectation shocks are uncorrelated.[4]

To carry out this experiment, we maintain the same baseline parameterization as in Table 1, except we assume that innovations to the persistent component of productivity and expectations are positively correlated. The correlation coefficient equals 0.8.

[Figure 5 goes about here]

[Figure 6 goes about here]

To conserve space, we only report the LIC responses for quantities in response to the two shocks. These appear in figures 5 and 6. For both, the qualitative features of the zero correlation impulse responses are very similar to those where the correlation between the two shock innovations equals 0.8.

The greatest difference is seen in the labor responses. In the initial period, the two responses are nearly identical. Recall that in response to a productivity shock, initial labor declines in order to work less when productivity is low. After a few periods, the central bank with uncorrelated shocks is relatively more confident that an expectations shock has occurred. With hindsight, this central bank recognizes that it undersupplied labor in the first few periods. To compensate, it increases employment in these future periods relative to the central bank with correlated shocks.

The difference between the uncorrelated and correlated labor response is positive, but small in magnitude. Thus, the increased employment leads to only a small output difference, as seen in figures 5(a) and (b).

[4]We thank Robert King for suggesting this extension of the model.

This intuition works for both shocks. The difference between the zero and positive correlation cases is greatest before the central bank has determined exactly which shock occurred and after its initial period of ignorance. The LID case gives very similar qualitative results and are not reported here.

4.2 Combining Limited Information and Discretion (LID)

In this subsection, we combine the assumptions of lack of commitment with limited information (hereafter, LID). We compare the LID case to the case of full information with commitment. The optimal responses of investment, consumption, the real interest rate and q in response to a θ shock are given in figure 7.

Under FIC, there is a positive response of investment. Under LID, investment is nearly unchanged in response to the shock. With limited information, the central bank with discretion must considers the (untrue) possibility that a positive productivity shock has occurred. If that were true, it would prefer to decrease investment initially instead of increase investment. The initial behavior of consumption if the shock were to productivity is for consumption to fall–because of intertermporal labor smoothing as described above. In panel B, consumption falls a small amount on impact and then begins to rise (as if a positive productivity shock is beginning).

[Figure 7 goes about here]

However, as the central bank sees less evidence of a true productivity increase, it becomes more confident that an expectations shock has occurred. By year 5, the central bank has consumption at the steady-state. Here it is useful to compare the consumption LID impulse response in panel B of this figure to corresponding FID response in figure 2(b). With discretion, consumption drops much more under full information than limited information. The uncertainty over whether an expectations shock has occurred greatly attenuates the central bank's response under discretion.

5 Conclusion

To the extent that non-fundamental asset price movements induce distortionary effects on real economic activity, there is a potential for a central bank to respond. Moreover, targeting nominal price inflation will not perform the same function as responding directly to non-fundamental asset price movements, as some authors have suggested, notably Bernanke and Gertler (1999).

Critics of using asset price movements to help inform monetary policy have claimed that, even if non-fundamental asset price movements exist, they are effectively impossible to distinguish from fundamental movements. Their recommendation is to ignore asset prices. This recommendation is not model-based. This paper has considered the role of limited information to evaluate this conjecture. We also consider how lack of commitment affects the optimal policy response to non-fundamental asset price movements.

For a sensibly calibrated model, the existence of limited information measurably, but not overwhelmingly, reduces the central bank response to potential non-fundamental asset price movements. This suggests that limited information may be less important than has been previously emphasized. More importantly, lack of commitment has a much larger effect on the optimal policy response to non-fundamental asset price movements. Optimal policy under discretion generates a longer and deeper recession in terms of consumption than under commitment.

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Figure 1: Real investment and stock market activity in the U.S. and U.K., 1990-2002

Figure 2: Impulse responses to an expectations shock, real quantities.

Caption for Fig. 2: Full information with commitment (FIC); limited information with commitment (LIC); full information with discretion (FID).

Figure 3: Impulse responses to an expectations shock, prices.

Caption for Fig. 3: Full information with commitment (FIC); limited information with commitment (LIC); full information with discretion (FID). Panel D contains real term structure in years 1 and 8 following the shock.

Figure 4: Impulse responses to a persistent productivity shock, real quantities.

Caption for Fig. 4: Full information with commitment (FIC); limited information with commitment (LIC); full information with discretion (FID).

Figure 5: Limited information with commitment response to an expectations shock: compares zero correlation between shocks (base) and positive correlation between shocks (corr).

Caption to figure 5: Correlation between expectations and persistent productivity shock in (corr) equals 0.8. Both cases are limited information with commitment (LIC).

Figure 6: Impulse responses to a persistent productivity shock: zero correlation between shocks (base), positive correlation between shocks (corr).

Caption to figure 6: Correlation between an expectations and persistent productivity shock in (corr) equals 0.8. Both cases are limited information with commitment (LIC).

Figure 7: Impulse responses to an expectations shock: comparing full information with commitment to limited information with discretion.

Caption to figure 7: Full information with commitment (FIC); limited information with discretion (LID).

Table 1: Baseline Specification

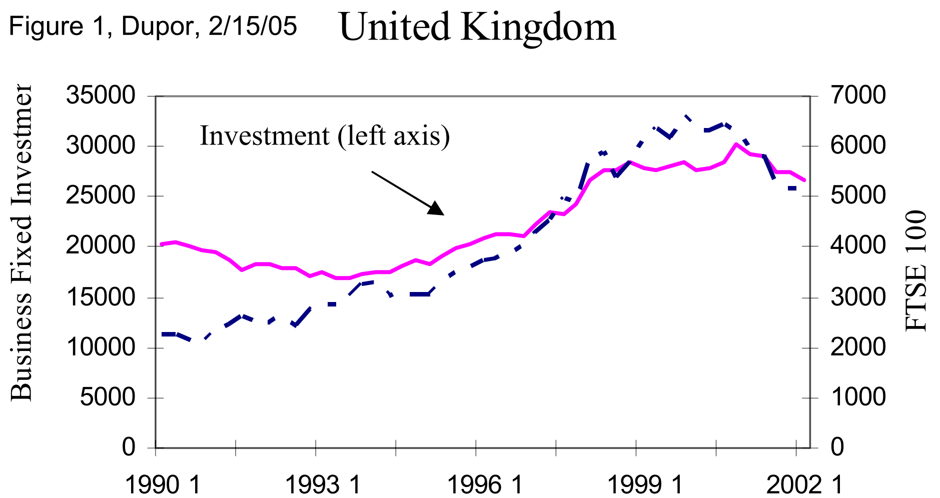
PARAM.	VALUE	MEANING	PARAM.	VALUE	MEANING
σ	1.5	coef. rel. risk aversion	A	1	disutility of work
β	0.95	utility discount factor	α	0.36	elasticity of *y* w.r.t. *k*
γ,G	100,100	cost of changing prices	δ	0.09	capital depreciation rate
Phi’’(1)	1	invest. adjust. cost	ϕ	-6	governs markup
$\sigma_{\varepsilon a}$	1.20	std. dev. *a* innovation	ρ_1, ρ_2,	.687,.679	persistence parameters
$\sigma_{\varepsilon\theta}$	0.60	std. dev. θ innovation	ω	0.50	shock parameter
			σ_{abar}	1.50	std. dev. iid tech. shock

Table 2: Parameterizing Shock Variances for the Limited Information Model

SD%	U.S. DATA	IID TFP ONLY (I)	BOTH TFP (II)	ALL SHOCKS LIC--(III)
Output	2.39	2.04	2.39	2.40
Consumption	2.15	0.65	0.64	0.65
Hours	1.79	1.12	1.11	1.11
Productivity	2.46	1.42	2.07	2.08
Average *q*	16.01	0.64	0.64	0.65
σ_{abar}	--	1.50	1.50	1.50
$\sigma_{\varepsilon a}$	--	0	1.20	1.20
$\sigma_{\varepsilon\theta}$	--	0	0	0.60

Notes: Annual data between 1954-2002 are used to calculate U.S statistics. Average *q* U.S. data is from Smithers and Wright (2000). Sample statistics for (I)-(III) are calculated by taking the averages of 50 model simulations of 100 periods each. Each series is detrended using an HP filter with smoothing coefficient equal to 400. LIC stands for ‘limited information under commitment.’

Figure 1, Dupor, 2/15/05



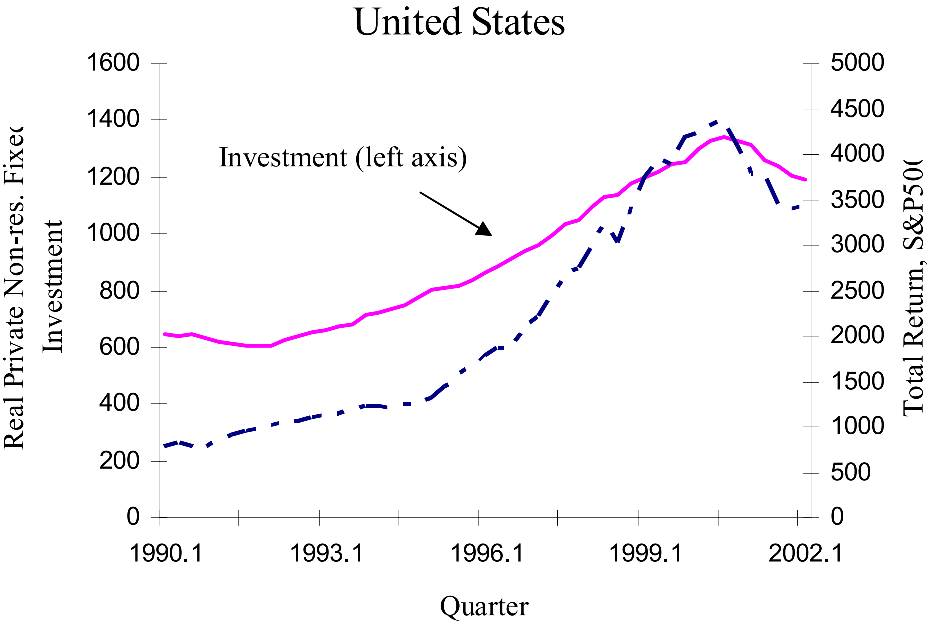


Figure 2, Dupor, 2/23/05

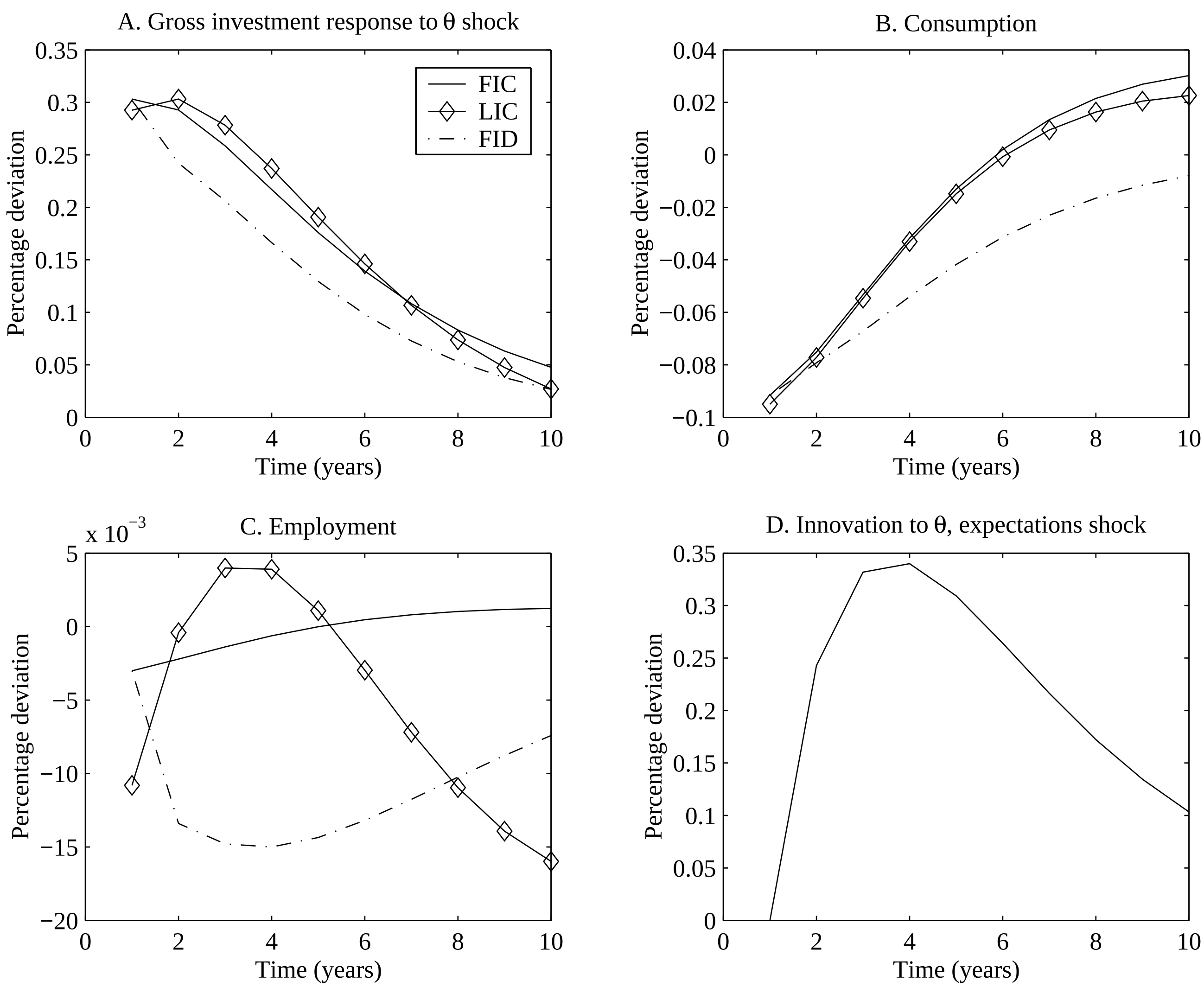


Figure 3, Dupor, 2/22/05

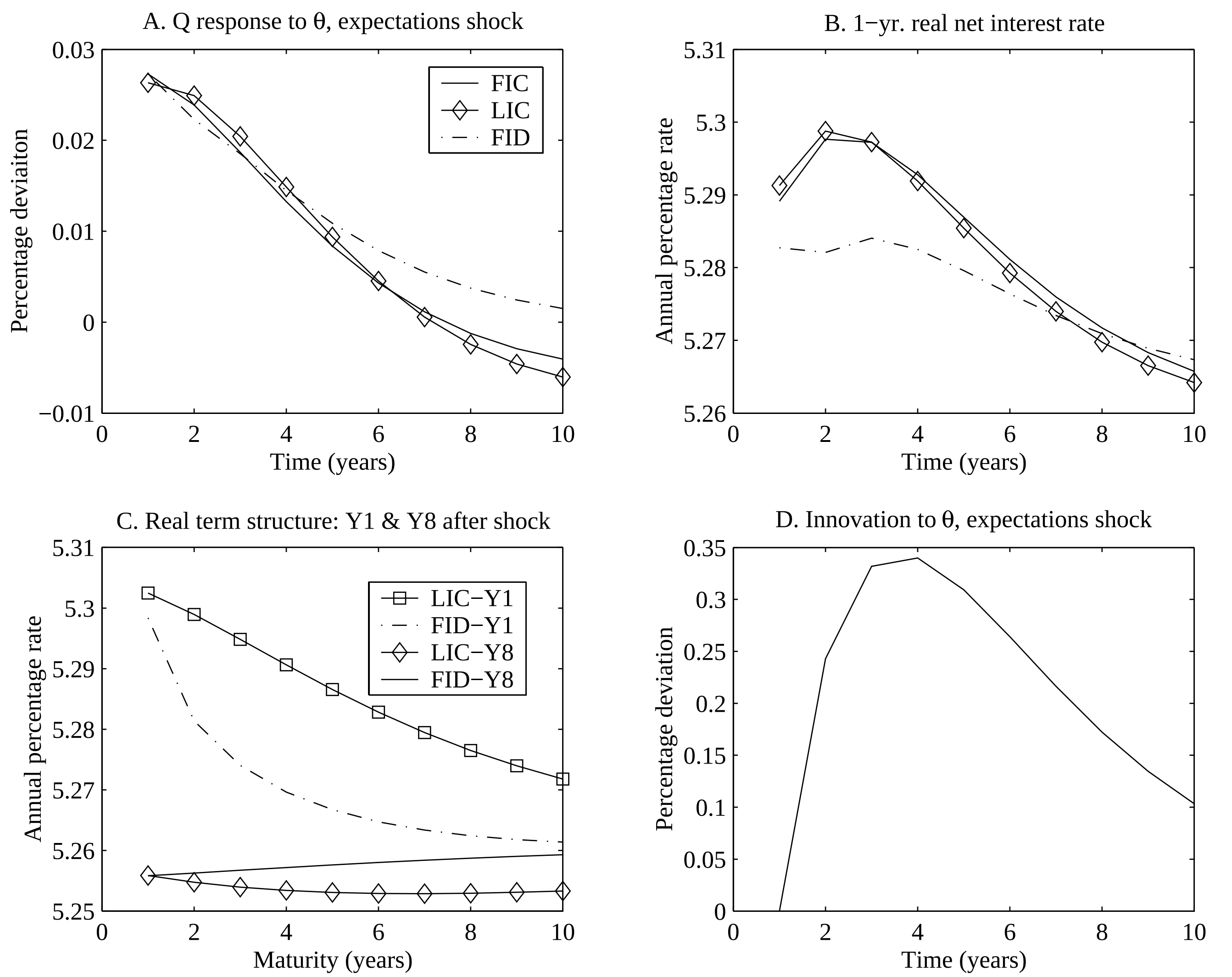


Figure 4, Dupor, 2/22/05

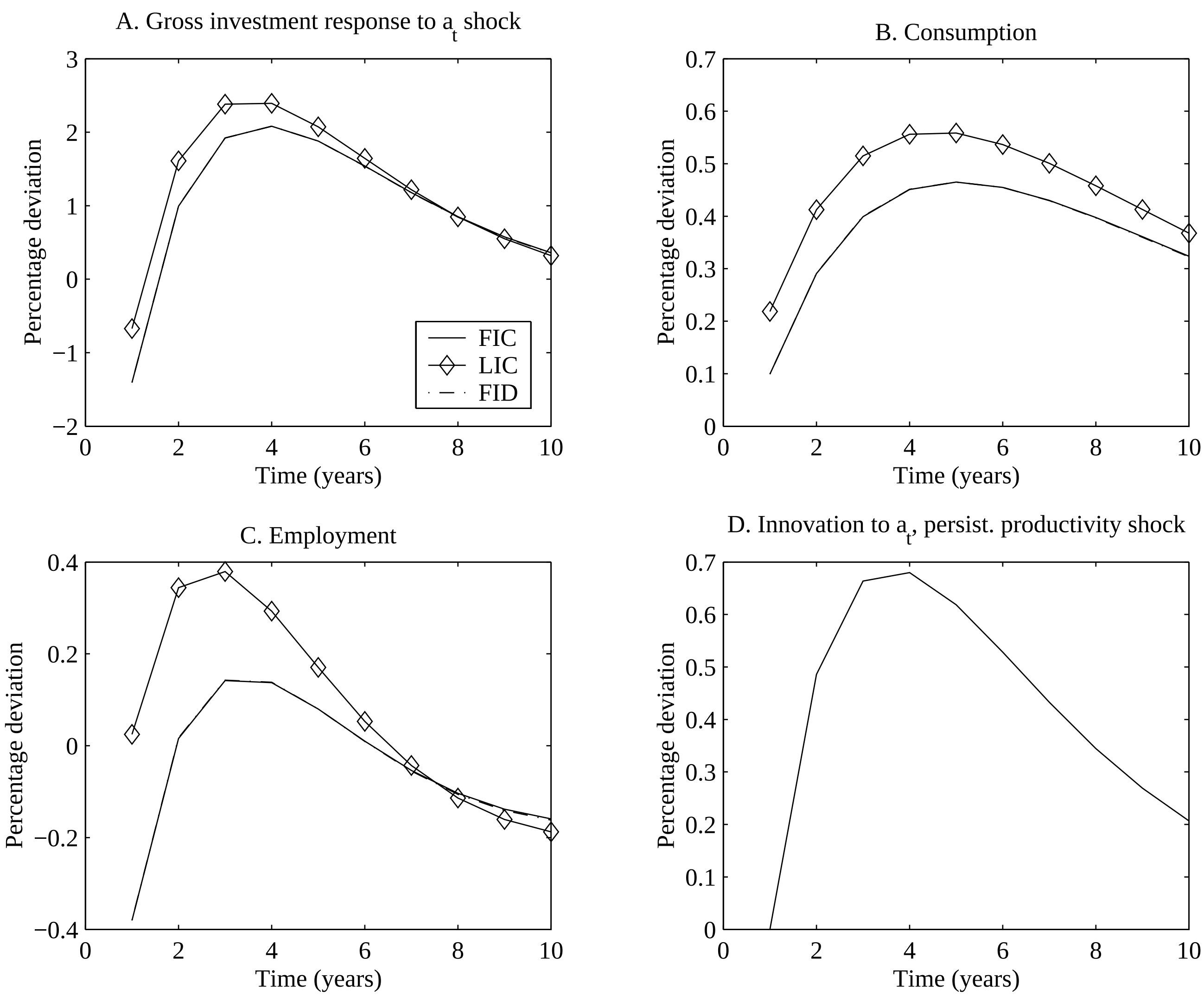


Figure 5, Dupor, 2/22/05

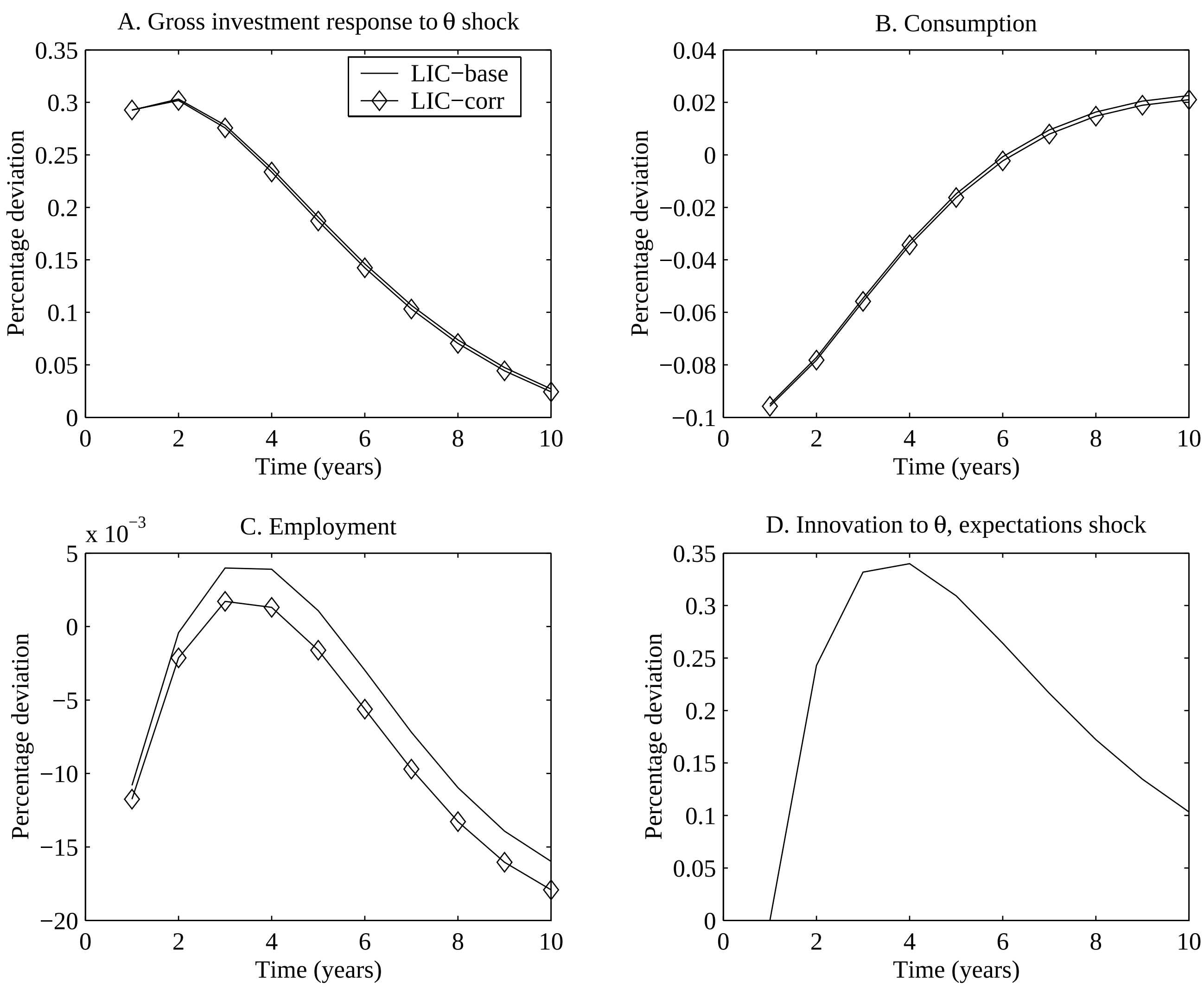


Figure 6, Dupor, 2/22/05

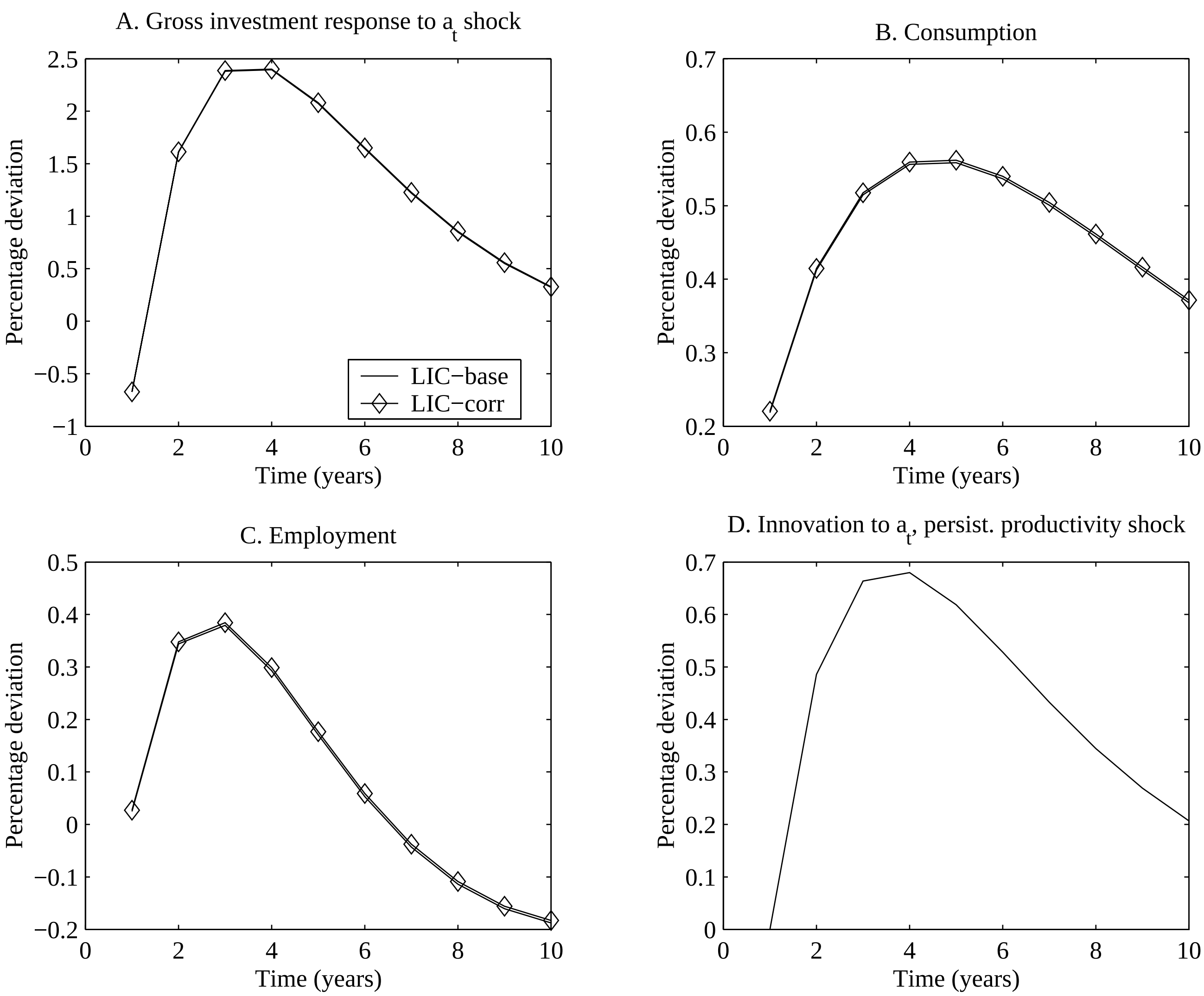


Figure 7, Dupor, 2/22/05