Nominal Price versus Asset Price Stabilization

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Abstract

This paper studies the optimal response of monetary policy under commitment to a distortionary shock to firms' investment demand. We consider a model with nominal price rigidity and convex investment adjustment costs. We document the desirability of and the trade-off between nominal price and asset price stabilization in response to this shock. Optimal policy is contractionary in response to an inefficient boom in investment and asset prices. By tightening policy, the monetary authority depresses the capital rental rate, partially offsetting the increased demand for investment, which reduces the value of installed capital and stabilizes asset prices. Relative to the optimal policy, nominal price stabilization generates short-run overinvestment and asset price inflation. In this and other sticky price models, nominal price inflation measures labor market distortion. The market price of the capital stock, through marginal q, usefully summarizes capital market distortion. We calculate significant relative welfare gains from following the optimal policy instead of nominal price stabilization in response to the shock.

1 Introduction

The 1990s saw tremendous gains in the stock market and a simultaneous sustained surge in physical investment in the U.S. Investment relative to the capital stock grew at a rate at least 4 percentage points above its post-WWII average in each year between 1994-1999. 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, consumer and producer price inflation remained low and stable.

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Proponents of the bubble view may cite overinvestment as one consequence of a non-fundamental asset price run-up. Asset price inflation may provide an indicator of capital overaccumulation, which cannot be gleaned from examining consumer or producer price inflation. This paper takes up a timely policy question: how should optimal monetary policy respond to movements in asset prices?[1]

We develop a sticky price-imperfect competition model with endogenous capital accumulation and investment adjustment costs. Capital good firms make investment decisions to maximize the expected present value of real profits. The model's only non-standard assumption is that firms sometimes misestimate the future return to currenct capital accumulation. These shocks drive investment and asset price movements in our model. Pareto efficiency only holds if firms neither over- nor underestimate the future returns to capital.

When firms overestimate the future returns to capital, they increase physical investment and asset prices appreciate. Our shock process delivers a model that matches two empirical macro phenomena: (a) the excess volatility of asset prices relative to fundamentals (as in Shiller 1981); (b) the correlation between non-fundamental asset price movements and physical investment (as in Blanchard, Summers and Rhee 1993 and Barro 1990).[2]

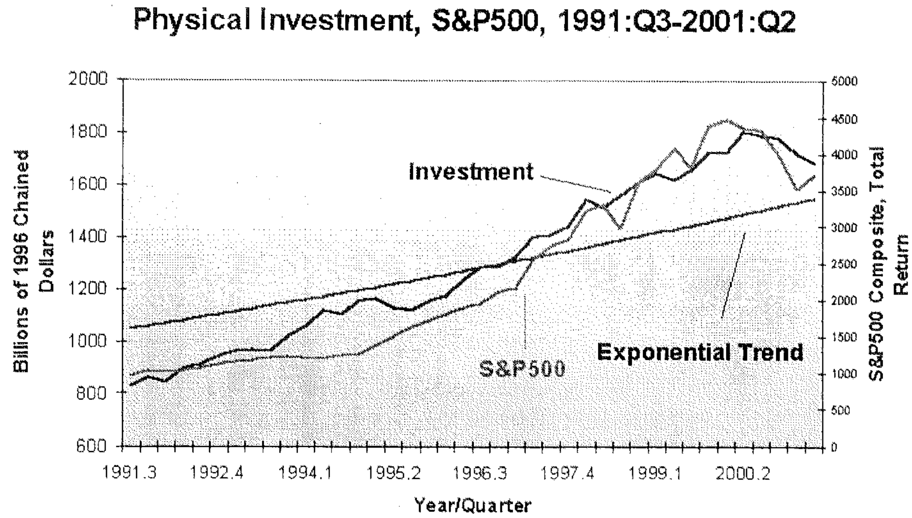
Adding to the macro evidence, the recent past has delivered many case studies of rapid stock-price appreciations followed by large purchases of equipment and structures. Consider the case of Webvan, founded in 1997 to deliver groceries ordered over the Internet as an alternative to traditional supermarket 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.

Some researchers, including Bosworth (1975), argue that even if firms should issue shares when stocks are overvalued because the equity cost of capital is low, these firms should not engage in physical investment in low return projects. Instead, the proceeds from these share issues should be invested in safe assets, such as Treasury bonds. Webvan's situation demonstrates practical difficulties with Bosworth's argument. First, by not expanding operations, Webvan could have risked lawsuits from shareholders for not following plans laid out in SEC filings. Second, the magnitude of the overvaluation was not exogenous to Webvan's actions. A sudden announcement of scaling back expansions would probably have hurt share prices. Corporate officers, major shareholders who may not have been able to sell their holdings due

[1]Our paper does not consider other important questions: (a) whether asset price changes should be included in a 'correct' measure of inflation (as discussed by Alchian and Klein (1973) and Goodhart (2001) for example); or (b) whether asset prices changes are important for monetary policy because they forecast future inflation (as discussed by Stock and Watson (2000) for example).

[2]Blanchard, Summers and Rhee (1993, p. 127) partially summarize their evidence stating "an increase of 1 percent in market valuation not matched by an increase in fundamentals leads to an increase in investment of 0.45 percent."

In 1997 and 1998, the market value of the S&P500 appreciated annually at approximately a 20 percent greater rate than its post-WWII average growth. Using this as a measure of the non-fundamental movement, this suggests 9 percent of investment growth would be attributed to non-fundamental stock price movements in each of the two years.



S&P500 (Dividends Reinvested) and Real Quarterly U.S. Investment. Source: Bureau of Economic Analysis, U.S. Department of Commerce; CRSP.

Figure 1: Investment and S&P500

to lock-out clauses, could have incentive to engage in physical investment to help maintain the overvaluation in the short-run. These two examples, together with the simple possibility that the company's directors were 'true believers', provides additional motivation for our approach.

Our model departs from rational expectations. Our approach is therefore related to several papers that explain asset pricing puzzles through deviations from rational expectations, including Cecchetti, Lam and Mark (2000) and Abel (2000). Like these papers, we assume rather than model the underlying reason for departure from rational expectations. Instead, our attention is trained on embedding this firm behavior in a model of optimal monetary policy. In response to these inefficient shocks to investment demand, optimal policy reduces both nominal price fluctuations and non-fundamental asset price movements. Here is the intuition for why each is a distinct and important target of optimal policy.

First, a benevolent monetary authority seeks to reduce nominal price inflation because it indicates distortion on the consumption-leisure margin. Under flexible prices, price-taking firms and wage-taking households generate an efficient allocation between consumption and work. With sticky prices, many authors find that nominal price stabilization implies either efficiency or constrained efficiency on this margin.[3] Under sticky prices with positive inflation, nominal prices are increasing because the marginal cost of employing an additional

[3] Since many sticky price models also feature imperfect competition, firms are not price takers. In order for zero inflation to imply consumption-leisure efficiency, a subsidy to labor is applied to undo the market power distortion. We follow this strategy, which is commonplace. See, for example, Rotemberg and Woodford (1997).

worker is too high relative to the marginal revenue product of hiring that worker. Because firms must meet demand at fixed nominal prices and the short-run capital stock is inelastic, labor is the sole adjusting factor.

Second, a benevolent monetary authority seeks to reduce non-fundamental movements in asset prices because these indicate distortion on the investment margin. When a firm overestimates the return to investment, this generates an increase in firms' perceived marginal value of capital q, which spurs physical investment. We assume an adjustment cost process which implies the equality of marginal and average q; therefore, the investment distortion can be read off the market value of the capital stock. Counteracting these distortionary (or non-fundamental) movements in asset prices helps correct inefficiency on the intertemporal margin.

With two marginal conditions, (a) consumption-leisure and (b) investment, and only one policy instrument, the optimal rule cannot in general recover the unconstrained efficient allocation. In other words, there is a trade-off between nominal price and asset price stability. Intuitively, it is suboptimal for the monetary authority to stabilize only one target (or, equivalently, correct only one marginal condition). Just as tax smoothing arguments imply that tax distortions should be spread across sectors and over time, optimal monetary policy spreads distortions across both margins (a) and (b).

Optimal policy partially corrects a distortionary increase in investment and associated asset prices. This is accomplished by contractionary monetary policy, which reduces equilibrium labor input. Lower labor input reduces the marginal product of capital, thus reducing the rental price of capital.[4] A lower rental rate reduces the incentive to accumulate capital, which counteracts the original distortionary shock. Effectively, a monetary authority behaving optimally creates nominal price deflation in order to offset asset price inflation. Nominal price stabilization, on the other hand, is *not* optimal because it ensures consumption-leisure efficiency while ignoring the investment distortion.

There is a third margin or distortion in the model: the direct 'menu costs' of nominal price inflation.[5] If this cost is large in the welfare function, monetary policy responds less to non-fundamental asset price movements because responding to asset prices induces nominal price fluctuations. In our simulations, we explore a wide range of these costs and find that for sensible calibrations, this third effect is relatively small.

Previous related research, most notably Bernanke and Gertler (1999, p. 18), argues for a smaller role for asset prices in forming monetary policy. Bernanke and Gertler (hereafter BG) state "policy should not respond to changes in asset prices, except insofar as they signal changes in expected inflation." Our argument is distinct: non-fundamental movements in asset prices signal distortions in the capital market to which optimal monetary policy should respond. Asset prices are important for optimal policy not because they are an indicator of nominal price inflation, but because they provide *different* information regarding market inefficiency than nominal prices.

[4]There are other channels for monetary policy to alleviate the distortionary investment shock which are less important quantitatively. We discuss these below.

[5]By menu costs, we mean the direct physical or utility cost of changing prices or loss of output created by relative price dispersion. We do not mean the extent to which inflation distorts real margins, such as the consumption-leisure decision.

Our approach differs from BG on two crucial dimensions.[6] First, BG assume the monetary authority cannot separately identify non-fundamental asset price movements. This severely limits a central bank's ability to counteract distortions generated by bubbles without doing collateral damage during fundamental asset price movements. On the other hand, we assume that a monetary authority can distinguish fundamental from non-fundamental (or in our language distortionary) changes. The truth lies somewhere inbetween. Pursuing the implications of our assumption is justified given the long-run predictability of asset returns (see, for example, Campbell, MacKinlay and Lo 1997). Particularly compelling is the record of financial economists, such as Shiller (2000), in identifying overvaluation during the recent stock market boom. Given the validity of BG's point, however, our welfare results should be read as upper bounds on the usefulness of asset price stabilization.

The second main difference is how policy rules are constructed. BG simulate a model under several interest rate rules, some of which respond to asset prices. We compute the optimal policy. Our approach is useful for two reasons: (a) the optimal policy may respond to asset price fluctuations even if simple ad hoc rules perform poorly;[7] (b) writing down the Ramsey program makes explicit the government's goal of using policy to make both the consumption-leisure equilibrium and intertemporal investment equilibrium conditions close to Pareto optimal. The former goal motivates nominal price stabilization, while the latter justifies reducing non-fundamental asset prices movements. Public finance instructs that policy should smooth distortions across time and markets. As such, distortionary shocks to physical investment demand should be counteracted with monetary policy—thus stabilizing asset prices—even at the cost of introducing some labor market distortion, and therefore nominal price fluctuations. To the extent that menu costs make nominal inflation bad for its own sake, the usefulness of policy responding to asset prices is reduced.

In the next section, we present a dynamic sticky price model with endogenous capital accumulation and distortionary investment shocks. Section 3 characterizes the model's equilibrium under two policies: nominal price stabilization and the optimal policy under commitment. Section 4 conducts a sensitivity analysis and welfare comparisons. Section 5 concludes.

2 A Sticky Price Model with Distortionary Investment Shocks

Household-Firm Problem

The economy is populated by many identical household-firms. Each maximizes its lifetime

[6] Other differences with BG seem to be less crucial. For example, we assume firms' forecast returns to capital incorrectly, which causes asset price and investment movements. BG assume a stochastic bubble as the exogenous forcing process and that firms are credit-constrained due to costly state verification. While the investment goods firms' own decisions are based on fundamental q (unlike our model), the bubble increases firms' net worth. Lenders take the bubble asset as good collateral, which lowers the external finance premium. A lower cost of capital leads to greater investment. In either case, someone's (firm in our model and lender in BG) confusion regarding an exogenous shock leads to a positive comovement of asset prices and investment. BG is certainly more elegant and has the additional benefit of a internal propogation mechanism through a financial accelerator. Our approach simplifies computation of optimal policy.

[7] The actual optimal rule does not respond to asset prices directly, but instead the underlying shock that drives asset pricing movements.

utility

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

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 $t \geq 0$. We assume $\sigma > 0$. Households dislike changing their own nominal price P_t rapidly. Here c_t denotes consumption, w_t the real wage, r_t the rental price of capital and M_t money holdings. Also, $\bar{P}_t$ denotes the aggregate nominal price index. Household-firms may hold only non-negative consumption and money $c_t, M_t \geq 0$. Finally, M_{-1} is given as an initial condition. Household-firms derive z_t from the profits of investment goods firms, which they own.

Household-firms hire $\tilde{n}_t$ workers from the labor market for own production and supply n_t own units of labor to other firms. The government subsidizes labor supply and capital rental, which it finances through lump sum taxes h_t. The magnitude of the subsidies are determined by s.

Monetary non-neutrality exists because household-firms face a quadratic utility cost of changing own prices.[8] At the same time, we assume household-firms also derive disutility, $G < 0$, or potentially positive utility, $G > 0$, from changes in the average price level:

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

Because household-firms take the general price level as given, v_t is external to the firm and does not affect first-order conditions. 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.

We further assume that households 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 generated by households attempting to economize on cash balances.

Household-firms are also subject to the constraint that given the price they charge P_t, sales are demand-determined:

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

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

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

[8] Rotemberg (1982) developed the original model with quadratic price adjustment costs. Benhabib, Schmitt-Grohe and Uribe (2000a, 2000b) and Dupor (2000) also use this specification.

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

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

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

Because it is not useful for our purposes, we omit the real balances equilibrium condition. Optimal price setting requires that equation (5) hold. Here, $\pi_t \equiv P_t/P_{t-1}$. Cost-minimization implies (6).

For the remainder of the paper, we assume that the government subsidizes labor and capital to generate steady-state Pareto efficiency: $1 + s = \phi/(1+\phi)$.[9] With this subsidy, the firm's pricing equation is

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

Intuitively, firms would like to set marginal revenue equal to marginal cost in each period (which equals price due to our 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:

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

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). This 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 effort. Second, it implies that in order to generate efficiency on this margin, a monetary authority should stabilize the price level $\pi_t = 1$, as in Rotemberg and Woodford (1997).

Many models share this aspect of our law of motion for inflation (7): inflation measures a sum of either current, future and/or past deviations of the marginal utility of consumption from an additional unit of work net of the disutility of work. For example, in Bernanke and Gertler (1999), the corresponding log-linearized expression appears in equations (A.10)-(A.11) of their paper. In the presence of subsidies to correct for market power, inflation measures the extent of current and expected future distortion on the consumption-leisure margin.

Investment Firm Problem

[9]This subsidy offsets the steady-state distortion of imperfect competition between houeshold-firms. The subsidy must be paid to both factors so that relative factor prices are not distorted.

In addition to household-firms that produce output and set nominal prices, investment firms determine capital accumulation. An investment firm's one-period real profits are:

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

where Φ is a nonnegative, convex adjustment cost function. At time t, firms perceived future profits are given by:

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

Investment firms do not issue new shares or bonds and are owned by households-firms.

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

$$\eta_t z_t + E_t \sum_{j=1}^{\infty} \left[\beta^j \eta_{t+j} \tilde{z}_{t+j}\right] \tag{8}$$

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

Our specification (8) is purposefully non-standard. In the typical case, $\theta_t = 1$. Firms invest inefficiently if $\theta_t \neq 1$. This assumption reflects our desire to understand how optimal policy should respond to *distortionary* shocks to an economy-wide investment schedule. This assumption is in keeping with Keynes' observation that significant fluctuations in investment—and a major cause of business cycles—are unexplained and may be driven by animal spirits.[10] Another interpretation is that non-fundamental and large movements in asset prices move physical investment through a q effect. A more sophisticated approach would first model asset price bubbles to explain why share prices appear to deviate for long periods from their fundamental value, as documented in Shiller (1981). Second, firm behavior would be modeled such that physical investment responds to non-fundamental movements in stock prices, as documented in Barro (1990) and Blanchard, Summers and Rhee (1993). Because asset prices and investment decisions are determined by firms' time varying and distortionary θ, our shock process shares both features of the more sophisticated approach.

The firm's investment decision satisfies:

$$1 + \Phi'(g_{t+1}) = \beta E_t \left[\left(\frac{c_t}{c_{t+1}}\right)^{\sigma} \left(\theta_{t+1} r_{t+1} + 1 - \delta - \Phi(g_{t+2}) + \Phi'(g_{t+2})\, g_{t+2}\right)\right] \tag{9}$$

where $g_{t+1} \equiv k_{t+1}/k_t$. Note that inflation does not appear in the above condition. Any effect of monetary policy on investment must work through the consumption-leisure condition—which involves inflation. Furthermore, if $\theta_{t+1} = 1$, equation (9) corresponds to the efficiency condition for investment.

[10] Another approach to modelling animal spirits is to assume a sufficiently strong strategic complementarity or interaction between economic agents (and potentially government policy) that leads to multiple equilibria. In the context of the conduct of monetary policy, this line is pursued by Dupor (2001).

In this section, we have modelled investment firms' deviation from rational expectations. We will also assume that household-firms share the investment firms expectations regarding future profits. This is a good assumption if household-firms do not believe that they have better information on future aggregate dividends than the investment firms. On the other hand, we assume that household-firms have rational expectations about the future cost of capital—expectations which are necessary to construct their forward-looking pricing policy. This is an appropriate assumption if household-firms are knowledgable about the particular capital input used in own production, but are not extremely knowledgable about *all of the economy's capital good producing firms.*[11]

Equilibrium

Collecting equilibrium conditions, we have three equations in four unknown stochastic processes $\{c_t, k_t, n_t, \pi_t\}$:

$$k_{t+1} = k_t^{\alpha} n_t^{1-\alpha} + (1-\delta)\, k_t - c_t - \Phi\left(\frac{k_{t+1}}{k_t}\right) k_t \tag{10}$$

$$\beta E_t\left[\left(\frac{c_t}{c_{t+1}}\right)^{\sigma}\left(\frac{\alpha A}{1-\alpha}\left(\frac{\theta_{t+1} n_{t+1} c_{t+1}^{\sigma}}{k_{t+1}}\right) + 1 - \delta - \Phi\left(\frac{k_{t+2}}{k_{t+1}}\right) + \Phi'\left(\frac{k_{t+2}}{k_{t+1}}\right)\frac{k_{t+2}}{k_{t+1}}\right)\right] = 1 + \Phi'\left(\frac{k_{t+1}}{k_t}\right) \tag{11}$$

and (7). The fourth and final equation is the monetary policy rule, specified below. We assume that, in expectation, firms discount correctly $E(\theta) = 1$. Then, in a stationary steady-state with zero inflation, the allocation is optimal because: (a) firms rationally forecast returns to capital; (b) there is no labor market distortion.

In the next section, we compute the equilibrium under the optimal monetary policy under commitment and compare it to a policy of nominal price stabilization.

3 Optimal Monetary Policy Under Commitment

Consider the problem of a benevolent monetary authority under commitment. A monetary authority chooses a stochastic process for $\{c_t, k_t, n_t, \pi_t\}$, subject to the resource constraint (10) and two incentive constraints (7) and (11), to maximize:[12]

$$E_0 \sum_{t=0}^{\infty} \beta^t \left[\frac{1}{1-\sigma}(c_t)^{1-\sigma} - A n_t - \frac{(\gamma - G)}{2}(\pi_t - 1)^2\right] \tag{12}$$

The Ramsey government choice cannot affect the quantity of equilibrium real balances, which are in perfectly inelastic demand.[13]

[11] The apparent asymmetry between expectations about future profits and rental prices of capital by household-firms results from the poor (but standard) assumption of the existence of a representative investment good firm.

[12] Given our inelastic real money demand specification, it is straightforward to back out the nominal money supply process which supports the optimal policy. Furthermore, the addition of nominal non-state contingent debt to the model would allow us to back out the implied interest rate under the optimal policy.

[13] Alternatively, we could have assumed that real balance demand is elastic but sufficiently unimportant in utility.

One special case is instructive by focusing on the model's two real distortions. It is additionally appealing to those who believe the menu costs of price changes have an inconsequencial effect on welfare in low inflation economies. This special case applies when $\gamma = G$. Since we restrict attention to symmetric equilibria, the internal and external effects on utility of price changes exactly offset. Then, we may ignore constraint (7) and π_t in the monetary authority's problem. This is possible because inflation appears in no other constraint nor the objective function. The expectational Phillips curve (7) allows the monetary authority to distort the consumption-leisure margin by choice of an inflation process. After computing the optimal policy without specifying $\{\pi_t\}$, we may back out an inflation process that satisfies (7).

The benevolent monetary authority, therefore, chooses a stochastic process for $\{c_t, k_t, n_t\}$ to maximize:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left\{ \begin{array}{c} \frac{1}{1-\sigma} (c_t)^{1-\sigma} - An_t + \lambda_t \left[k_t^{\alpha} n_t^{1-\alpha} + (1-\delta) k_t - c_t - \Phi\left(\frac{k_{t+1}}{k_t}\right) k_t - k_{t+1} \right] + \\ \mu_t \left[\beta E_t \left[\left(\frac{c_t}{c_{t+1}}\right)^{\sigma} \left(\frac{\alpha A}{1-\alpha} \left(\frac{\theta_{t+1} n_{t+1} c_{t+1}^{\sigma}}{k_{t+1}} \right) + 1 - \delta - \Phi\left(\frac{k_{t+2}}{k_{t+1}}\right) + \Phi'\left(\frac{k_{t+2}}{k_{t+1}}\right) \frac{k_{t+2}}{k_{t+1}} \right) \right] - 1 - \Phi'\left(\frac{k_{t+1}}{k_t}\right) \right] \end{array} \right\} \tag{13}$$

The Ramsey problem associated with (13) can also be interpreted as arising from a second, non-monetary, economy. Consider the *real* neoclassical growth model. There exists a government that has no expenditure requirements and may levy lump-sum financed taxes or subsidies on wages. The government cannot tax or subsidize capital income, even though there is a distortionary shock θ to investment demand.

Under this second interpretation, a labor market equilibrium condition does not appear in (13) because the government may select a labor tax or subsidy to make any labor allocation consistent with an equilibrium. Without redress from capital subsidies, the government may want to deviate from a zero labor tax (or a monetary authority may want to deviate from price stability) in order to undo a distortion caused by the investment equilibrium condition. In either the non-monetary or monetary interpretation, a benevolent government balances the potential market distortions.[14]

We discuss the first-order conditions for $\{n_t, c_t, k_{t+1}\}$ in turn. First, for all $t > 0$, optimal labor n_{t+1} satisfies:

$$\mu_t E_t \left[\left(\frac{\alpha A}{1-\alpha} \right) \frac{\theta_{t+1} (c_t)^{\sigma}}{k_{t+1}} \right] = \beta E_t \left[A - (1-\alpha) \lambda_{t+1} \left(\frac{k_{t+1}}{n_{t+1}} \right)^{\alpha} \right] \tag{14}$$

The RHS of (14) is roughly the discounted deviation of the social planner's static consumption-leisure Euler equation.[15] In the unconstrained optimal allocation, the RHS equals zero. In the Ramsey problem, the RHS equals zero if and only if the incentive constraint does not bind $\mu_t = 0$, or, in other words, investment is allocated efficiently. If $\mu_t > 0$, firms underestimate returns to capital and therefore underinvest. In response, the monetary authority chooses greater labor input next period relative to the static social optimum. The policy's marginal effect is to raise the discounted next period rental price of capital. Intuitively,

[14] The first-order conditions introduce lagged multipliers into the model's dynamic equations as in Khan, King and Wolman (2000). We treat the lagged multipliers as additional state variables, along with d_t and k_t.

[15] The only difference is that λ_t does not represent simply the shadow value of consumption, but also the effect of consumption on the incentive compatibility constraint.

raising the capital rental price by inducing greater future labor supply partially offsets the distortion.

Second, consider the optimal consumption c_{t+1} for all $t > 0$. We state the first-order condition without investment adjustment costs for simplicity.

$$\sigma \beta E_t \left\{ \mu_{t+1} \left[\frac{(c_{t+1})^{\sigma-1}}{(c_{t+2})^{\sigma}} \left(\frac{\alpha A}{1-\alpha} \left(\frac{n_{t+2}}{k_{t+2}} \right) \theta_{t+1} (c_{t+2})^{\sigma} + 1 - \delta \right) \right] \right\} = \tag{15}$$

$$E_t \left\{ \lambda_{t+1} - (c_{t+1})^{-\sigma} + \sigma \mu_t (1-\delta) \left[\frac{(c_t)^{\sigma}}{(c_{t+1})^{\sigma+1}} \right] \right\} \tag{16}$$

When the incentive constraint does not bind in the current or future period $\mu_t = \mu_{t+1} = 0$, the Ramsey and unconstrained optimal programs both imply that the marginal utility of consumption equals the shadow value of output.

Consider the situation when $\mu_t > 0$ and $\mu_{t+1} = 0$, implying underinvestment between t and $t+1$ and efficient investment between $t+1$ and $t+2$. In this case, $(c_{t+1})^{-\sigma} > \lambda_{t+1}$. In absence of the time t incentive constraint, c_{t+1} would be too low. What is the benefit of the Ramsey government depressing next period consumption?

With zero adjustment costs, increasing the capital stock k_{t+1} through current investment pays: (i) the expected capital rental price next period r_{t+1}; and (ii) the expected return on the undepreciated capital $1-\delta$, where both (i) and (ii) are priced using the stochastic discount factor $\beta (c_t/c_{t+1})^{\sigma}$. A decrease in c_{t+1} raises the stochastic discount factor, thus increasing the return to physical investment through (ii). Intuitively, reduced consumption in the next period increases the return to having more undepreciated capital available for consumption then. Thus, decreasing c_{t+1} partially offsets the distortionary decrease in investment demand.[16] A similar relationship explains the role of μ_{t+1}.

Third, consider the optimal capital choice k_{t+1} for all $t > 1$. We again abstract from adjustment costs for simplicity.

$$E_t \left\{ \beta \lambda_{t+1} \left[\alpha \left(\frac{k_{t+1}}{n_{t+1}} \right)^{\alpha-1} + 1 - \delta \right] - \lambda_t \right\} = \beta \mu_t E_t \left[\frac{\alpha A}{1-\alpha} \left(\frac{\theta_{t+1} n_{t+1} (c_t)^{\sigma}}{(k_{t+1})^2} \right) \right] \tag{17}$$

If $\mu_t = 0$, (17) is the efficiency condition for capital accumulation from the unconstrained social optimum. As stated above, if $\mu_t > 0$, then the Ramsey solution sets the expected social marginal return to capital next period greater than the opportunity cost of investing. There is underinvestment from a social perspective.

Equations (14) and (17) together deliver the optimal allocation between labor and capital, under the special case of no investment adjustment costs:

$$\beta E_t \left[A - (1-\alpha) \lambda_{t+1} \left(\frac{k_{t+1}}{n_{t+1}} \right)^{\alpha} \right] E_t (n_{t+1}) = E_t \left[\beta \lambda_{t+1} \left(\alpha \left(\frac{k_{t+1}}{n_{t+1}} \right)^{\alpha-1} + 1 - \delta \right) - \lambda_t \right] k_{t+1} \tag{18}$$

[16] There is an offsetting wage effect that implies changes in c_{t+1} do not affect the return to investment in (i).

The braced terms on the left- and right-hand side of (18) represent the deviation of next period labor and capital from the optimum in marginal utility terms. The optimal policy equates these two distortions weighted by the expected quantities of labor and capital at time $t+1$. During periods of underinvestment, the RHS is positive. To make (18) hold, the Ramsey government sets the marginal disuility of work to be greater than the marginal utility of consumption derived from that work. That is, the LHS is positive when labor at $t+1$ is oversupplied from a static social perspective.

In the next section, we solve the model in the general case where $\gamma \neq G$.

Model Simulation

Our technique for analyzing the system dynamics requires selection of model parameters. These parameters are given in Table 1. The coefficient of relative risk aversion σ, returns to capital α, capital depreciation rate δ are within the standard range of calibration values. One period lasts three months. The disutility of work A is a scale parameter that has no effect on important ratios or equilibrium dynamics. The parameter ϕ governs degree of substitutability between final goods. The markup in a zero inflation steady-state equilibrium $\phi/(\phi+1)$ equals 25 percent.

Next, we select a household discount factor $\beta = 0.995$. The implied annual steady-state real interest rate is 2 percent. The parameter γ multiplies the quadratic cost of changing own nominal price for household-firms. It also governs the speed of nominal price adjustment. The selection of γ is discussed in detail in Dupor (2001).

The parameter G was chosen to match empirical evidence concerning the welfare cost of inflation volatility as viewed by a central bank. Söderlind (1999) estimates that in the U.S. between 1966:II and 1995:IV, the Fed policy rule gave 4.55 times the weight to output volatility relative to inflation volatility in its objective function, Λ in our notation. We chose G to match this figure, where consumption volatility is replaced with output volatility in our model. In an extension we consider alternative 'direct' costs of inflation since we do not wish to take a stand on whether the Federal Reserve was overly or underly responsive to inflation during the period.

Table 1: Benchmark Specification

Parameter	Value	Meaning
σ	4	coef. of relative risk aversion
β	0.995	household utility discount factor
A	1	disutility of work
α	0.36	returns to capital
δ	0.03	capital depreciation
f_1, f_2, ω	0.9,0.89.0.5	invest. shock param. process
ϕ	-5	governs markup
γ	100	private cost of changing prices
$\Phi''(1)$	20	investment adjustment cost
Λ	4.55	weight on Var(c) relative to Var(π)

We select $\Phi(1) = \Phi'(1) = 0$, which implies average and marginal investment adjustment costs are zero at the steady-state. We chose $\Phi''(1) = 20$, which together with the capital depreciation rate, implies an elasticity of i/k with respect to q equal to 1.66. Empirical estimates including Kiyotaki and West (1996) and Cummins, Hassett and Hubbard (1994) find lower adjustment costs than used here. Choosing a conservatively high adjustment costs biases our findings towards little benefit from asset price stabilization because a low elasticity of investment demand implies little room for distortion.[17]

The law of motion for the distortionary investment shock process is:

$$\theta_t = \omega\theta_{1,t} - (1-\omega)\,\theta_{2,t} \tag{19}$$

where

$$\theta_{i,t} = f_i\theta_{i,t-1} + \varepsilon_t \text{ and } E_t(\varepsilon_{t+1}) = 0 \tag{20}$$

If $1 > \omega > 0.5$ and $1 > f_1 > f_2 > 0$, then a positive shock to ε_t generates a positive initial and hump-shaped impulse response function for θ; therefore, the impact of the shock builds over time as given by (19)-(20) and then asymptotes to the initial steady-state value. The lower right panel of figure 2 gives the time path of θ in the simulation.

There are two stages in our solution technique. First, set the exogenous shock equal to its steady-state value and solve for the unique steady-state. Next, log-linearize the model around the steady-state and compute optimal policy impulse response functions.

Results

Below we compute the optimal impulse response functions (IRF) of several real quantities to a distortionary shock to investment. For comparison with the optimal policy, we also compute the IRF under a zero inflation target; that is, where $\pi_t = 1$ for all t. Recall equation (7), the equilibrium law of motion for inflation:

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

Under the zero inflation policy, when labor input is positive the law of motion for inflation implies:

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

in every period. In this case, the monetary authority maintains an efficient allocation between consumption and leisure and generates no menu costs.

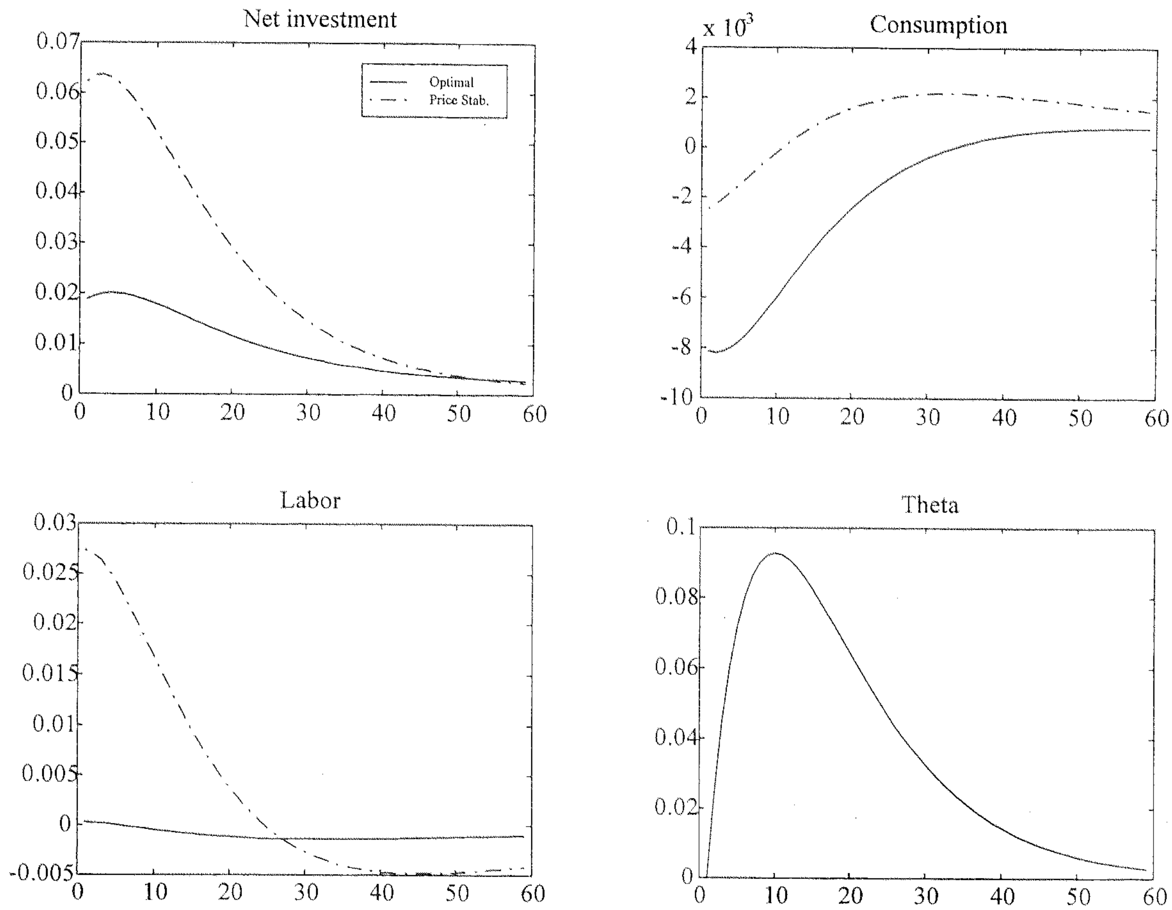
Figure 2 plots the optimal and zero inflation IRFs, on the solid and dotted lines respectively, for investment, labor, consumption and the shock θ.[18] An increase in θ implies that firms overaccumulate capital relative to the social optimum. This can be seen by solving forward a log-linear approximation to the equilibrium investment equation (9). Letting $\hat{x}_t = \log(x_t/x^*)$, we have:

$$\hat{k}_{t+1} - \hat{k}_t = \frac{1}{\Phi''(1)}\sum_{j=0}^{\infty}\beta^j\left[\beta r^*\hat{r}_{t+j+1} + \beta r^*\hat{\theta}_{t+j} - \sigma\left(\hat{c}_{t+j+1} - \hat{c}_{t+j}\right)\right] \tag{21}$$

[17] We consider a more standard specification in section 4 by following BG and setting the elasticity equal to 4.

[18] For every IRF, the initial period lagged multipliers are set to their steady-state values.

Figure 2: Optimal and price stabilizing IRFs to distortionary investment shock



In the initial period of the shock, investment rises over 6 percent in the zero inflation policy and less than 2 percent under the optimal policy. The optimal policy counteracts over two-thirds of the initial inefficient investment increase that obtains under inflation targeting.[19]

According to (21), a key determinant of current investment is the future capital rental rate. The monetary authority can counteract the increased investment by reducing the future capital rental price. This is accomplished by depressing labor market activity through contractionary monetary policy, thus reducing the marginal product and rental rate of capital. The capital rental rate IRF is in the lower-right panel of figure 3. This is also clear from examining the Ramsey government's Euler equation for labor input (14). Note that the optimal policy generates a decrease in labor input, while the zero inflation policy generates an increase.

Next, consider the two consumption IRFs. Both paths initially have consumption below

[19]Since the shock is a pure distortion, the unconstrained socially optimal IRF is a flat line at zero. The optimal and zero inflation policies cannot replicate the first-best response.

the steady-state and increasing. In both cases, the increase in investment demand is partially met by allocating current output away from consumption. Consumption eventually surpasses its steady-state level and then asymptotes to the steady-state from above under the price stabilizing policy. Once the investment shock dissipates, the price stabilizing economy is left with overaccumulated capital—which households run down through above steady-state consumption. Using monetary policy to manipulate consumption growth provides another mechanism for a central bank to offset a distortionary shock. By generating a steeply sloped consumption profile, the monetary authority would raise the opportunity cost of investing, as seen in (21). This channel does not appear quantitatively important since the optimal and price stabilizing consumption paths grow at roughly the same rate.

It is worth noting our modelling approach may understate the costs of actual investment demand shocks driven by non-fundamental asset price movements. In our model, an additional unit of installed capital–due to the distortionary shock–is inefficient; however, it is only slightly less productive than the last unit of capital installed in absence of the shock. In reality, stock price run-ups may occur in sectors where physical investment turns out to be ex post much less productive than the existing capital stock, which would imply a much smaller consumption boom in the medium run. During the late 1990s, millions of venture capital dollars were spent developing and advertising internet retail shops and delivery services that never got off the ground.

Nominal Price versus Asset Price Stabilization

Inflation targeting leads to larger increases in the value of installed capital in response to a distortionary investment shock than the optimal policy. Optimal policy dampens the movement in the value of capital. To accomplish this, the monetary authority introduces nominal price deflation. Our results, therefore, document an explicit trade-off between nominal price and asset price stabilization.

Standard models of investment often define the discounted expected marginal value of capital in the following period as q. We define q in this manner using the distorted expectations on returns. This will be useful because our q will then be a sufficient statistic for investment–as in the standard approach. Let

$$q_t \equiv \beta E_t \left[\left(\frac{c_t}{c_{t+1}} \right)^{\sigma} \left(\theta_{t+1} r_{t+1} + 1 - \delta - \Phi\left(g_{t+2}\right) + \Phi'\left(g_{t+2}\right) g_{t+2} \right) \right]$$

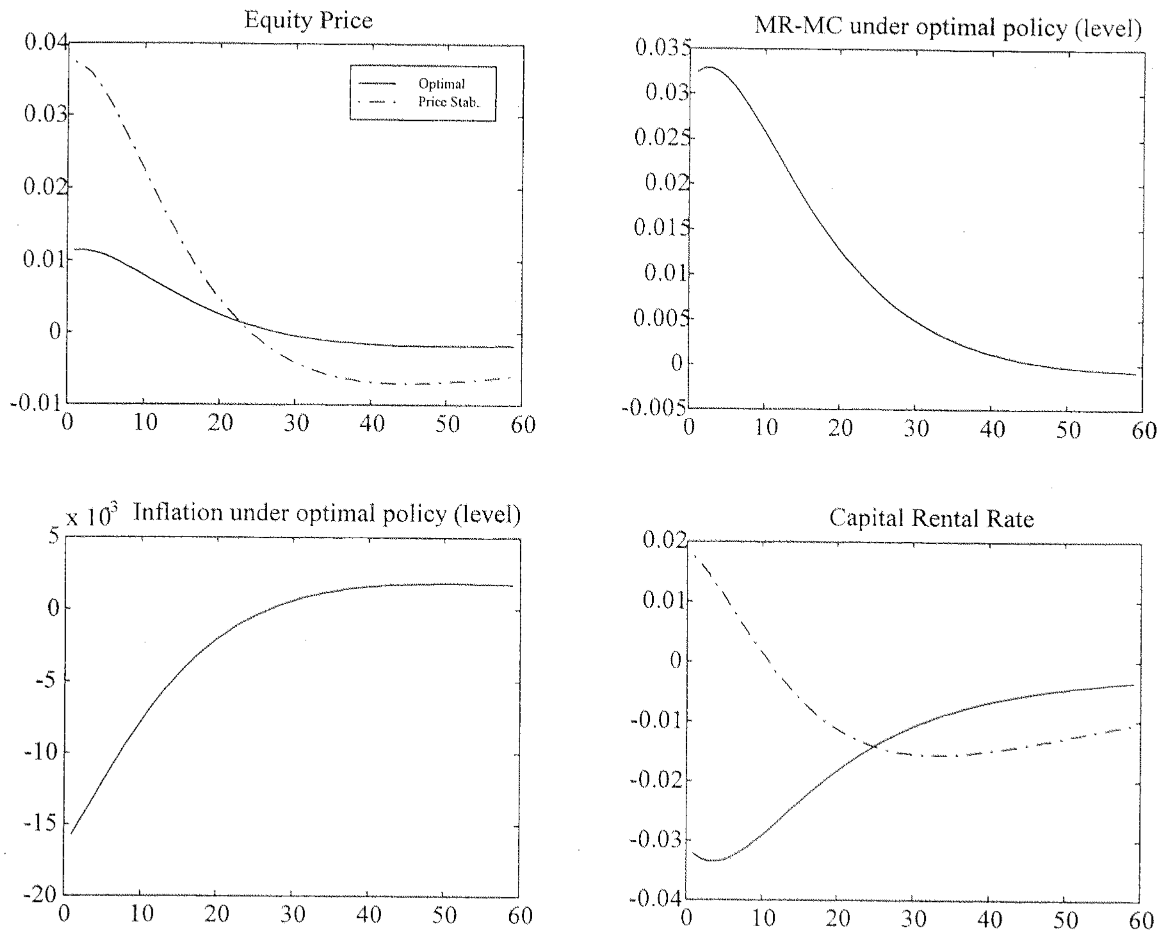
Equation (9) implies that, in equilibrium,

$$q_t = 1 + \Phi' \left(\frac{k_{t+1}}{k_t} \right)$$

Given our adjustment cost specification, marginal and average q, from the investment firms' perspective, are identical.

The upper-left panel of figure 3 shows that nominal price stabilization involves a more volatile response of the price of equity than the optimal policy. Since a monetary authority effectively ignores the distortionary investment shock under this rule, there is a much larger response of investment. With convex adjustment costs, this raises the value of existing capital.

Figure 3: Optimal and price stabilizing IRF for equity prices; optimal MR-MC and inflation IRFs



Note: Equity price & capital rental rate in perc. dev. terms.

Our benchmark specification induces similar responses in investment (6 percent under price stability) and q (approximately 4 percent under price stability). Recall that in their baseline estimate, Blanchard, Summers and Rhee estimate that a 1 percent non-fundamental increase in market value implies a 0.44 percent increase in physical investment. Our benchmark model gets these relative magnitudes reversed. Increasing the adjustment costs to investment would help match the Blanchard, Summers and Rhee estimate.

Note also that there is significant overshooting of q under inflation targeting. By the fifth year following the initial shock, marginal q falls below its steady state and continues declining for several years. Overaccumulation of capital drives this result. The optimal policy, on the other hand, dampens the investment movement—which induces a smaller response in q. The economy which overaccumulates capital by stabilizing nominal prices experiences several years of lackluster stock market performance once the shock dissipates.

Next, consider the optimal inflation response. Recall that current inflation depends upon the discounted sum of current and expected future deviations of marginal cost from marginal revenue. The upper-right panel shows the path of these deviations in response to the investment shock (under the optimal monetary policy). In response to the persistent increase in θ_t, monetary policy is conducted to increase marginal revenue relative to marginal cost. Given our assumed wage and capital rental subsidies, in a static sense, labor is too low relative to consumption. Reducing labor input is optimal because it offsets the inefficient increase in investment demand. The monetary authority drives a wedge between marginal revenue net of marginal cost, which works exactly as a tax on labor supply. The dampened response of labor under the optimal policy relative to the zero inflation policy is due to this 'effective' labor tax. The optimal inflation IRF is plotted in the lower-left panel of figure 3. Monetary policy induces a deflation. Since marginal revenue is above marginal cost on the transition path, firms lower nominal prices. On the other hand, the price stabilizing policy sets implies no distortion on the consumption-leisure margin. Comparing the upper and lower left panels of figure 3, there is a clear trade-off between nominal and asset price stabilization.

The optimal policy in response to distortionary investment shocks features a novel form of time inconsistency. Due to the shock, a monetary authority optimally discourages *current* investment by depressing the *future* rental price of capital by committing to contract the money supply and reduce labor activity next period; however, once the future arrives and the investment has already been discouraged, the monetary authority no longer needs to distort the labor margin. Failure to observe a central bank respond to non-fundamental movements in equity prices may result from lack of commitment—not from other possible explanations, such as an inability to distinguish fundamental from non-fundamental asset price fluctuations.

4 Alternative Specifications and Welfare Analysis

4.1 Varying the Direct Welfare Costs of Inflation

There are three margins for distortion in the model: two 'neoclassical' margins, leisure and investment, and the third—the direct welfare cost of inflation. To offset a distortionary increase in the economy-wide investment schedule, the monetary authority should tighten monetary policy. By slowing economic activity in the short-run, the expected future return to capital is reduced. Investment and the price of equity are stabilized. Adopting this policy has two negative effects on welfare: it distorts the consumption-leisure margin, and it destabilizes the nominal price level.

In the previous section, we calibrated the direct welfare cost of inflation based upon estimates of the Federal Reserve's aversion to inflation. In the benchmark specificaiton, the volatility of consumption gets a relative weight of 4.5 times that of the volatility of inflation in the household welfare function. These direct costs of inflation are the 'menu costs', such as time cost of changing prices and the efficiency loss of price dispersion.

The direct welfare cost of nominal inflation volatility is a matter of debate. First, many authors, including Mankiw (1985), argue that the large welfare costs of inflation arise not from the direct 'menu costs' of inflation, but instead from the effect these menu costs have on keeping output off its Pareto efficient level. In our notation, Mankiw's primary cost of inflation corresponds to the consumption-leisure distortion it generates. For researchers who believe menu costs have little direct welfare costs, a large value of Λ is appropriate. Other authors, such as Rotemberg and Woodford (1997), argue that inflation leads to measurable direct welfare costs if firms engage in asynchronous price setting. Since we do not model price setting in this manner, the term $-(\gamma - G)(\pi_t - 1)^2/2$, in the social welfare function (12), can be thought of as approximating this distortion. If the welfare cost of asynchronous price setting are large, a small value of Λ is appropriate. Finally, we calibrated the social welfare function to estimates of the Federal Reserve objective function; however, even if these estimates are accurate, it is possible that the Federal Reserve does not maximize consumer welfare.

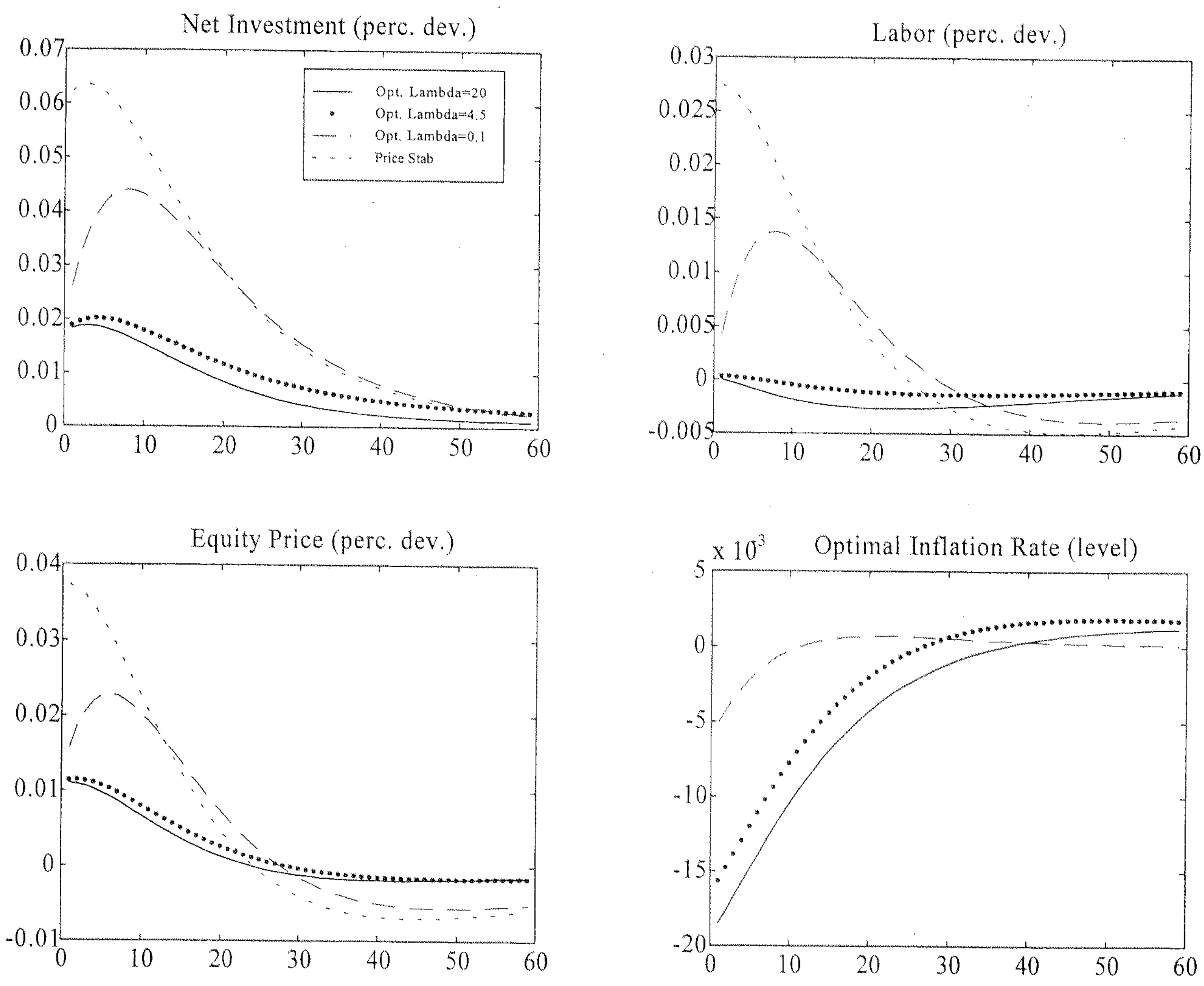
For these reasons, we consider alternative weights on the direct welfare cost of inflation relative to the benchmark model. Figure 4 plots the optimal and price stabilizing IRFs for several endogenous variables and various values of Λ.[20] All other parameters are maintained at their benchmark values. Not surprisingly, larger direct costs of inflation (smaller Λ) push the optimal IRF closer to the price stabilizing policy. The price stabilizing IRFs are identical across different specifications of Λ.

The main conclusion of Figure 4 is that even under the extreme assumption that $\Lambda = 0.1$, where inflation volatility is ten times as costly as consumption volatility, the optimal response to a distortionary investment shock is dramatically different from nominal price stabilization. Even with strong preferences towards price stability, the monetary authority still attempts to stabilize investment and the price of equity in response to the shock. On impact, the price of equity price rises by almost 4 percent under price stabilization and less than 2 percent under the optimal policy. On impact, investment rises over 6 percent under price stabilization and only 2.5 percent under the optimal policy. In the next section, we compare welfare across policy regimes for different values of Λ and we will see that large welfare benefits from responding to non-fundamental asset price movements remain even when $\Lambda = 0.1$.

Along this dimension, our model is biased against finding a strong role for monetary policy in responding to asset price changes. While we include a potentially large direct welfare cost of nominal price fluctuations, we do not include any welfare cost of asset price fluctuations (apart from the real distortionary effects on investment). Stiglitz (1989), Summers and

[20] To vary Λ, we fix the private cost of price changes γ–which determines the coefficient on marginal revenue minus cost in the forward-looking Philips curve, and vary the social cost of price changes G.

Figure 4: Optimal and price stabilizing IRF: varying direct welfare cost of inflation



Summers (1989) and Eichengreen, Tobin and Wyplosz (1995), for example, argue that a transactions tax would reduce what they view is the inefficient volatility of equity prices. We have not included any direct costs of equity price volatility in this model.

4.2 Varying Investment Adjustment Costs

As part of our sensitivity analysis, we change the degree of investment adjustment costs by setting $\Phi''(1) = 8.3$, which implies an elasticity of i/k with respect to q equal to 4: the same elasticity chosen by Bernanke and Gertler. All other parameters are chosen to be identical to their baseline values.

The upper-left panel of figure 5 demonstrates that lower adjustment costs increase the response of investment to the shock under both the optimal and inflation targeting policies. In addition, the difference between the investment IRFs under the optimal and price stabilizing policy is much larger under low investment adjustment costs. This is intuitive. Optimal policy should smooth distortions across different margins. If investment demand is extremely elastic because of small adjustment costs, then there is a larger effect on quantities of the original shock.

Even though investment moves a great deal under the lower adjustment costs, the optimal labor IRFs under high and low adjustment costs both show a flat response of labor input in the response to the shock. The central bank generates significant static labor market distortion through monetary policy to undo overaccumulation of capital in both cases. Likewise, optimal inflation is very similar under high and low investment adjustment costs.

Smaller adjustment costs move our equity variable around less. Under the price stabilization policy, marginal (and average) q move roughly 4 percent initially in response to the shock with the benchmark adjustment costs relative to 2.5 percent with low adjustment costs.

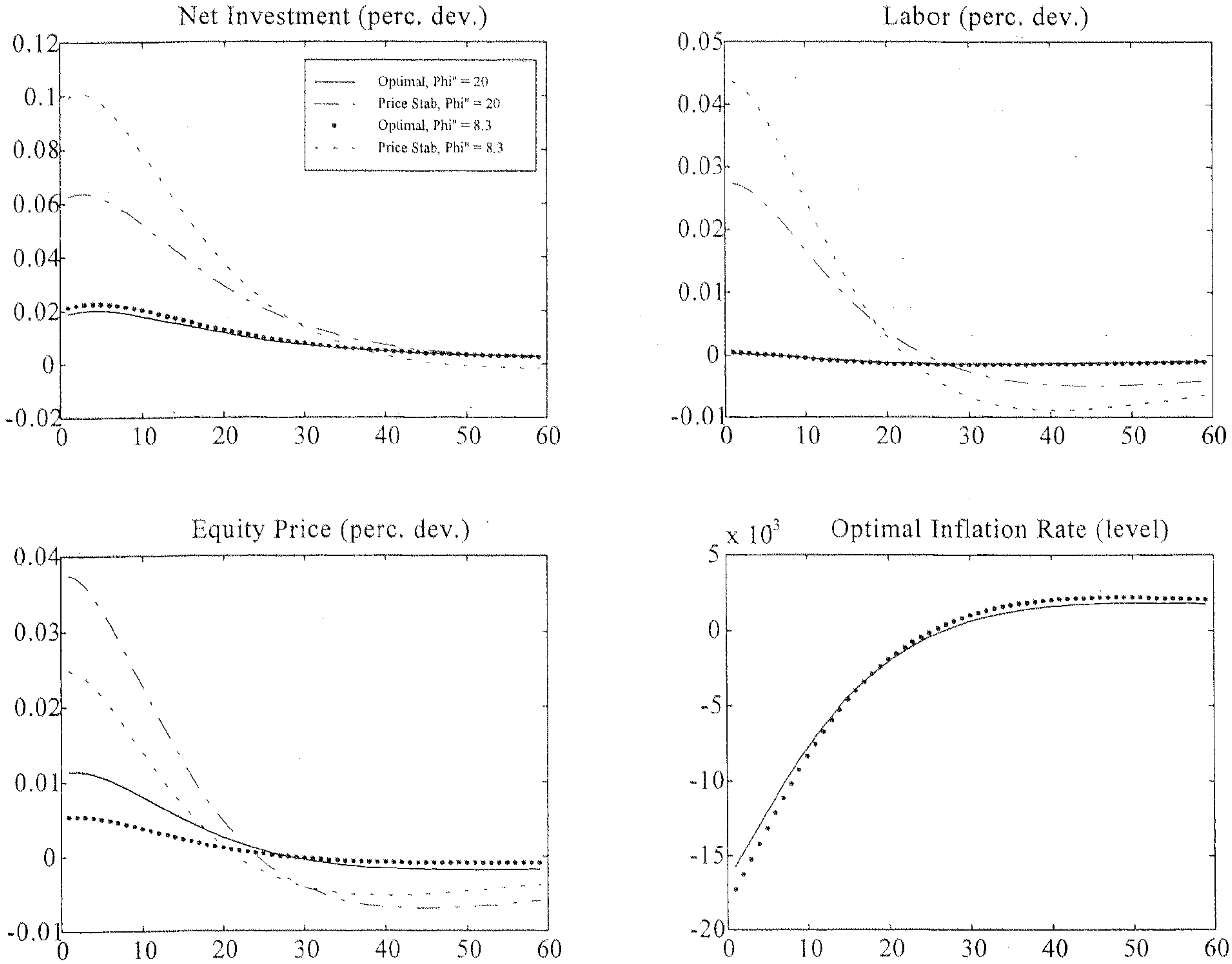
4.3 Welfare Analysis

In this section, we calculate the welfare costs of the shock under both policies. We compute welfare measures using consumption equivalents. First, we compute the time zero utility of a household that experiences the distortionary shock under both the price stabilization and optimal policy. We assume that the economy begins at an initial steady-state capital stock. Also, the optimal policy depends upon non-physical state variables—lagged Lagrange multipliers from the incentive constraints. We set the initial values of the multipliers equal to their long-run steady-states in these calculations.

For comparison, we offer the household the opportunity to not experience the shock. In exchange, the household maintains labor effort at the steady-state n^*, but receives a constant consumption stream below the steady state. Let c_{opt} denote the consumption equivalent under the optimal policy and c_π the equivalent under inflation targeting. Each consumption equivalent just makes the household indifferent between experiencing and not experiencing the shock.

The table below presents three statistics from four calibrations. The final two columns contain the percentage of steady-state consumption households would forego to avoid the shock under the optimal and price stabilizing policies. Not surprisingly, the welfare costs are small under either policy rule. These are one time, temporary shocks. The absolute welfare

Figure 5: Optimal and price stabilizing IRF: comparing baseline with Bernanke-Gertler investment adjustment costs



costs of consumption fluctuations are small. Note that smaller consumption losses arise when capital adjustment costs are high $\Phi''(1) = 20$. Also, the largest consumption loss, -0.3357%, occurs under inflation targeting with the BG adjustment costs. Low investment adjustment costs imply a high investment demand elasticity. Consider the case of perfectly inelastic investment supply. If adjustment costs are infinite, then θ shocks do not lead to misallocation of physical capital. In this case, nominal price stabilization is optimal because distortion is only possible on the consumption-leisure margin. Similarly, the benefits of optimal policy over nominal price stabilization are decreasing in the magnitude of adjustment costs—or equivalently, the inelasticity of the short-run investment supply.

Table 2: Welfare Calculations

	Z	$\log(c_{opt}/c^*)$	$\log(c_\pi/c^*)$
Baseline Investment Adjust. Cost			
$\Lambda = 4.55$,[21]	67.62%	-0.0678%	-0.2098%
$\Lambda = 0.10$	40.06%	-0.1257%	-0.2098%
$\Lambda = 20.0$	69.87%	-0.0632%	-0.2098%
BG Investment Adjust. Cost			
$\Lambda = 4.55$	77.15%	-0.0766%	-0.3357%
$\Lambda = 0.10$	51.68%	-0.1621%	-0.3357%
$\Lambda = 20.0$	78.76%	-0.0712%	-0.3357%

Even if the overall welfare costs of the investment shock are small, we would still like to compare the efficacy of inflation targeting relative to the optimal policy. The second column presents one such measure. It reports $Z \equiv (c_{opt} - c_\pi) / (c^* - c_\pi)$. If inflation targeting is not optimal, then this ratio delivers a positive percentage value less than 100. It asks, apart from the entire size of the cost of a distortionary shock to investment, what fraction of this cost may be avoided by selecting optimal policy over inflation targeting? Since lower adjustment costs imply a greater desire for firms to inefficiently substitute into investment, lower adjustment costs raise the welfare benefits of following optimal policy. This is true in our simulations. For the benchmark $\Lambda = 4.55$, going from the high baseline investment adjustment cost to the lower value used by BG implies that the welfare savings improve from 67.62% to 77.15%.

Figures 6 and 7 plot Z as the magnitude of direct welfare cost of nominal inflation, indexed by Λ, and the investment adjustment costs $\Phi''(1)$ vary. A larger value of Z implies a greater welfare gain from optimal policy over nominal price stabilization in response to the shock. For figure 7, the welfare gains are larger under low relative to high adjustment costs for every Λ. For figure 6, Z declines monotonically in the size of the investment adjustment costs. The lowest value of $\Phi''(1)$ on the horizontial axis of 6 is 3.3. For the given depreciation rate, this implies an elasticity of i/k with respect to marginal q equal to 10. The largest value of $\Phi''(1)$ is 111, which implies a corresponding elasticity of 0.3.

Next, as Λ increases, the direct welfare cost of inflation declines. For an implausiably low value of $\Lambda = 0.01$, (which implies the relative weight on inflation volatility is 100 times

[21] This is the welfare calculation for the benchmark model.

Figure 6: Welfare cost avoided by choosing optimal instead of price stabilizing policy: varying investment adjustment cost.

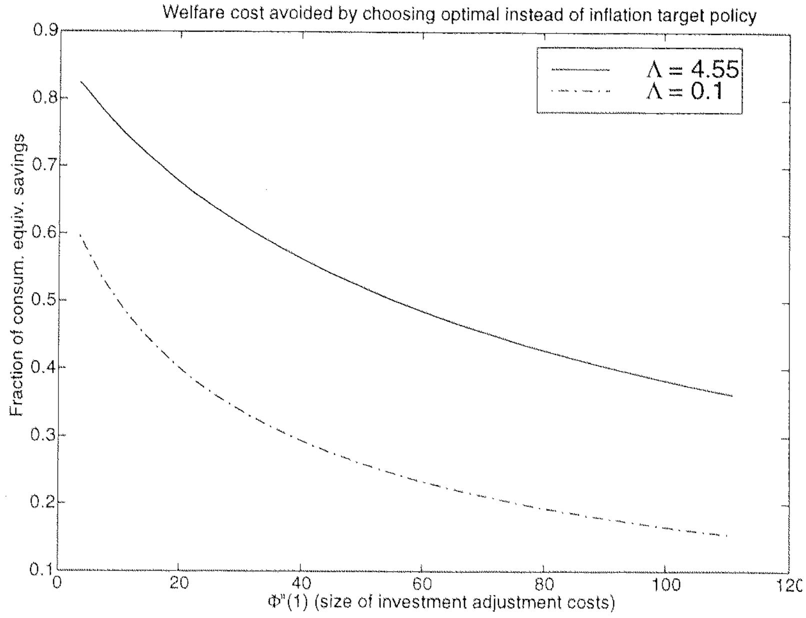
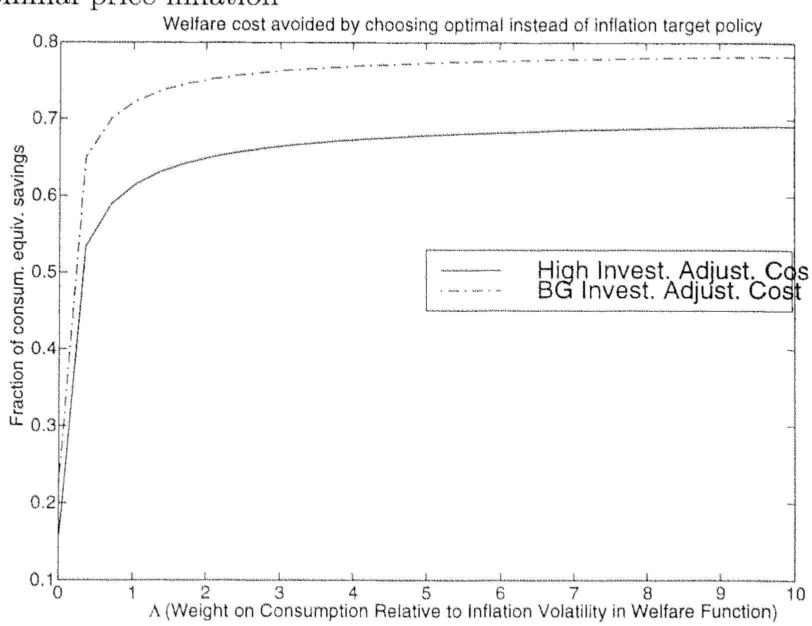


Figure 7: Welfare cost avoided by choosing optimal instead of price stabilizing policy: varying direct cost of nominal price inflation



that of consumption volatility), there is pratically no improvement of the optimal policy over nominal price stabilization. For plausible values of Λ, figure 7 demonstrates that there are signifigant welfare gains from following the optimal policy relative to nominal price stabilization.

5 Conclusion

In this paper, we have studied the optimal monetary policy response to distortionary shocks to an economy's investment schedule. When firms overestimate the returns to capital, they increase physical investment. Because of adjustment costs, observed average q, and therefore the price of equity, also rise. The central bank responds optimally by tightening monetary policy. With sticky prices, this raises the real price of goods. Higher real goods prices reduce demand, thus decreasing the labor input required to meet demand at fixed nominal prices. The reduction in labor lowers the marginal product and rental rate of capital. A lower rental price of capital partially offsets the increase in demand for investment goods and equity prices. Therefore, to counteract the distortionary shock, optimal policy introduces nominal price deflation. Our paper has, therefore, provided a formal justification for a monetary authority to respond to non-fundamental movements in asset prices at the expense of nominal price stabilization. For all reasonably calibrated versions of the model, there are significant relative welfare gains from pursuing the optimal policy relative to simple nominal price stabilization.

Two remaining questions merit discussion here. First, as mentioned in the introduction, we assume the monetary authority may distinguish non-fundamental movements in asset prices. While a strong assumption, it is no stronger than analyses in models without endogenous investment where the monetary authority always knows the natural rate of unemployment or full-employment level of output. More research is required in understanding the degree of model uncertainty faced by a monetary authority with regard to how far off both market-determined labor and investment decisions are from their efficient levels. Moreover, we conjecture that a monetary authority may effectively–from the standpoint of consumer welfare–be able to respond to a non-fundamental asset price run-up even if it cannot exactly time the market peak. Slowing the rate of inefficient physical investment when asset prices rise does not require the monetary authority to know precisely when the run-up will end. This is a very different problem from that of an active investor, facing margin requirements on short sales, attempting to time the market for the sake of profit.

Second, researchers have used quadratic loss functions over output and inflation to compare monetary policies. In a model without endogenous investment, Rotemberg and Woodford (1997) derived such a loss function as a second-order approximation to the utility function of the representative agent. An indirect utility function with inflation and output as the only arguments is no longer valid once endogenous investment is introduced. In this case, the welfare across alternative monetary policy regimes depends not only upon the level of aggregate output but also how the components of output vary in response to the shock. We leave to future research developing micro-founded loss functions that include investment.

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