

Inflation Risk and Optimal Monetary Policy

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ABSTRACT

This paper shows that the optimal monetary policies recommended by New Keynesian models still imply a large amount of inflation risk. We calculate the term structure of inflation uncertainty in New Keynesian models when the monetary authority adopts the optimal policy—the policy that minimizes the gap between output in the New Keynesian model and output in a flexible wage and price model. When the monetary policy rules are modified to include a small weight on a price path, the economy achieves equilibria with substantially lower long-run inflation risk. With sticky prices, the price path target reduces long-run inflation uncertainty with no measurable increase in the variability of the output gap. With sticky wages, a tradeoff exists between short-run output stabilization and long-run inflation risk.

The views expressed in this paper are those of the authors and do not necessarily reflect official positions of the Federal Reserve Bank of St. Louis, the Federal Reserve System, or the Board of Governors.

“Indeed, given our inevitably incomplete knowledge about key structural aspects of our ever-changing economy, ... a central bank seeking to maximize its probability of achieving its goals is driven, I believe, to a risk-management approach to policy.” (Alan Greenspan, Jackson Hole, August 2003).

I. Introduction

Significant progress has been made in adapting modern macroeconomic models for use in policy analysis. Although there is a broad consensus for using general equilibrium models with optimizing agents, little agreement exists about which particular model to use. This paper focuses on the inflation risk that is inherent in New Keynesian models with optimal monetary policy.

Monetary economists have recently focused on determining the optimal monetary policy in New Keynesian models. King and Wolman (1999) and Woodford (2003) show that the optimal monetary policy in a sticky price framework invariably involves stabilizing inflation expectations. When wages are also sticky, Erceg, Henderson, and Levin (2000) find that the monetary authority should stabilize both price inflation and output. Building on that work, Canzoneri, Cumby, and Diba (2004) show that wage stickiness should lead policymakers to target wage inflation. Kim and Henderson (2005), in related work, analytically derive the optimal monetary policy in a model with one-period price and wage contracts. They show that the optimal policy replicates the output path from a flexible price and wage specification. Hence, one can approximate the welfare loss in New Keynesian models by computing the variability of the output gap where the gap is defined as the difference between the output paths in the models with and without nominal rigidities.

An important distinction between New Keynesian models and the real economy is the relative importance of long-run inflation uncertainty. In New Keynesian models, long-run inflation uncertainty is typically not a source of welfare loss. In reality, policymakers closely

monitor long-term interest rates and try to develop policies that work well in the presence of long-run uncertainty. Investors pay to ensure against long run risks. Although the fundamental risk that concerns policymakers and investors may be in the real growth trend—as in Orphanides and Williams (2002), Bansal and Yaron (2004), or Ries (2005), uncertainty about long-run inflation will confound attempts to measure and price it. The purpose of this paper is not to model the reason why long-run inflation uncertainty matters. Rather, it is to evaluate the relative performance of monetary policy rules on this dimension.

In this paper, we show that optimal monetary policy in New Keynesian models produces a great deal of uncertainty about inflation at medium to long horizons. We analyze a modified policy rule that includes some weight on a price path. The modified rule substantially reduces long-run inflation variability regardless of the types of nominal rigidities. Nominal frictions, however, influence the impact that a price path target has on output stabilization. With sticky prices, the price path target reduces long-run inflation uncertainty with no measurable increase in the variability of the output gap. With wage stickiness, a tradeoff exists between short-run output stabilization and long-run inflation risk.

A price path target also performs well when the underlying structure of the economy is uncertain. Researchers have analyzed policy in models with uncertainty about the estimates of parameters within a particular structure, about the data corresponding to important theoretical concepts in the model, and about the fundamental structure.¹ This paper shows that targeting a price path works well in a world where the data generating process switches among alternative models with differing sources of nominal rigidities.

¹There is a large literature on monetary policy under uncertainty. Prominent examples include early work by Brainard (1967) that has been extended recently by Tetlow and von zur Muehlen (2001) and Brock, Durlauf, and West (2003). Hansen and Sargent (2002, 2004) and Onatski and Stock (2002) use robust control theory to evaluate

The remainder of the paper proceeds as follows. Section II describes a general model. Section III discusses the calibration assumptions that are common to all the models and the assumptions about nominal rigidities that distinguish among them. Section IV shows how the sticky wage and price models behave as policymakers approach the optimal policy, both with and without policy shocks. We also show how those policies work in the uncertain model. Then, we examine the effect of the policy rules on uncertainty about expected inflation. Finally, we analyze the consequences of price path targeting. Section V concludes.

II. The Model

A New Keynesian model is developed that nests the three alternative versions used in this paper: a flexible model, a sticky price model, and a sticky wage model. The three versions share many common features: the utility function, specification for money, and policy rule. They all have distortions associated with monopolistic behavior in both the goods and labor markets. Modest investment adjustment costs are included to keep the real effects of policy from being too large on impact in the sticky price and sticky wage models. Our model includes exogenous disturbances to the monetary policy rule, preferences, and technology. As in Ireland (2005), the monetary policy shocks comprise both highly persistent shocks to the inflation target and less persistent liquidity shocks to the short-term interest rate. This section outlines a dynamic stochastic general equilibrium model with both sticky prices and sticky wages, but then indicates the calibrations that convert the price and wage setting rules into flexible specifications.

Households: Each household is an infinitely lived agent who participates in state contingent securities markets. That assumption enables households to be homogenous with

policy in econometric models. Cogley and Sargent (2004) analyze policy in a model where the Fed is learning which

respect to consumption investment, capital, money, and bonds. Household h values consumption, c_t , and real money balances, (M_t/P_t) , but dislikes labor. Those preferences are summarized by the following expected utility function:

$$E_t \left[\sum_{i=0}^{\infty} \beta^i a_{t+i} \left(\ln(c_{t+i}^*) + \kappa \frac{n_{h,t+i}^{1+\sigma_1}}{1+\sigma_1} \right) \right],$$

where the consumption bundle is an aggregate of the consumption good and real balances,

$$c_t^* = \left((c_t)^{(\sigma_2-1)/\sigma_2} + b \left(\frac{M_t}{P_t} \right)^{(\sigma_2-1)/\sigma_2} \right)^{\sigma_2/(\sigma_2-1)}.$$

E_t is the conditional expectation at time t and β is the discount factor. The preference parameter, a_t , resembles an aggregate demand shock and evolves such that:

$$\ln(a_t) = \rho_a \ln(a_{t-1}) + v_{a,t},$$

where $0 \leq \rho_a < 1$ and $v_{a,t} \sim N(0, \sigma_a^2)$.

Households are monopolistically competitive suppliers of differentiated labor services to the firms. Total labor hours utilized by the firms, n_t , is calculated as a Dixit and Stiglitz (1977) continuum of labor hours, $n_{t,h}$, supplied by each household, $h \in [0,1]$:

$$n_t = \left[\int_0^1 (n_{h,t})^{\varepsilon_w/(\varepsilon_w-1)} dh \right]^{(\varepsilon_w-1)/\varepsilon_w},$$

where $-\varepsilon_w$ is the wage elasticity of demand for household h 's labor services. Cost minimization by the firms yields the demand equation for household h 's labor services:

$$n_{h,t} = \left(\frac{W_{h,t}}{W_t} \right)^{-\varepsilon_w} n_t,$$

of three versions of the Phillips Curve works best. See Dennis (2005) for an overview of the literature.

where $W_{h,t}$ is the nominal wage rate of household h and W_t is interpreted as the aggregate nominal wage rate:

$$W_t = \left[\int_0^1 (W_{h,t})^{(1-\varepsilon_w)} dh \right]^{1/(1-\varepsilon_w)}.$$

Households own the capital, k_t , in this economy and supply it to the firms. Every period, household h chooses a level of investment, i_t , such that:

$$k_{t+1} - k_t = \phi(i_t / k_t)k_t - \delta k_t,$$

where $\phi(\cdot)$ is a functional form for capital adjustment costs and δ is the depreciation rate. The functional form, $\phi(\cdot)$, represents Hayashi (1982) style capital adjustment costs, where the resources lost in the conversion of investment to capital equals $i_t - \phi(i_t / k_t)k_t$. Those lost resources are an increasing and convex function of the steady state investment-to-capital ratio such that $\phi'(\cdot) > 0$ and $\phi''(\cdot) < 0$.

Household h begins each period with an initial level of nominal money balances, M_{t-1} , and receives a payment, $R_{t-1}B_{t-1}$, from its nominal bond holdings, B_{t-1} , where R_t is the gross nominal interest rate earned on bonds during period t . During the period, household h receives labor income, $W_{h,t}n_{h,t}$, dividends from the firms, D_t , a lump-sum transfer from the monetary authority, T_t , a payment from the state contingent securities markets, $A_{h,t}$, and rental income from capital, $P_t q_t k_t$, where q_t is the real rental rate of capital. Those resources then are used to fund consumption and investment purchases and end-of-the-period bond, B_t , and money, M_t , holdings. The budget constraint for household h is represented as follows:

$$B_t + P_t(c_t + i_t) + M_t = W_{h,t}n_{h,t} + P_t q_t k_t + D_t + R_{t-1}B_{t-1} + T_t + M_{t-1} + A_{h,t}.$$

Finally, household h chooses a level of c_t , i_t , k_t , B_t , and M_t that maximizes its expected utility subject to its capital accumulation and budget constraint equations.

Wage contracts between households and firms can last for multiple periods. As a result, household h must determine each period whether or not an opportunity exists to negotiate a new nominal wage, $W_{h,t}$, for its labor services, $n_{h,t}$. Using the Calvo (1983) model of random adjustment, the probability that household h can set a new nominal wage, W_t^* , is η_w , and the probability that its nominal wage can only rise by the steady state inflation rate, π , is $(1 - \eta_w)$. The nominal wage is perfectly flexible in this specification when η_w is set equal to 1. When household h has a wage adjustment opportunity, it selects a nominal wage which maximizes its utility given the firms' demand for its labor:

$$W_t^* = \left[\left(\frac{\chi \varepsilon_w}{\varepsilon_w - 1} \right) \frac{E_t \left[\sum_{i=0}^{\infty} \beta^i (1 - \eta_w)^i (W_{t+i} \pi^{-i})^{\varepsilon_w (1 + \sigma_1)} (n_{t+i})^{1 + \sigma_1} \right]}{E_t \left[\sum_{i=0}^{\infty} \beta^i (1 - \eta_w)^i (P_{t+i} \pi^{-i})^{-1} (W_{t+i} \pi^{-i})^{\varepsilon_w} n_{t+i} (c_{t+i}^*)^{(1 - \sigma_2) / \sigma_2} (c_{t+i})^{-1 / \sigma_2} \right]} \right]^{\frac{1}{\varepsilon_w \sigma_1 + 1}},$$

where $(1 - \eta_w)^i$ is the probability that household h will not have an opportunity to negotiate a new nominal wage in the subsequent i periods.

Firms: Firms, owned by the households, are monopolistically competitive producers of differentiated goods. Firm f hires labor, $n_{f,t}$, and rents capital, $k_{f,t}$, from the households to produce its output, $y_{f,t}$, according to a Cobb-Douglas production function:

$$y_{f,t} = Z_t (k_{f,t})^\alpha (n_{f,t})^{(1 - \alpha)},$$

where Z_t is an economy wide productivity factor and $0 \leq \alpha \leq 1$. The productivity factor, Z_t , evolves such that:

$$\ln(Z_t) = \rho_Z \ln(Z_{t-1}) + (1 - \rho_Z) \ln(Z) + v_{Z,t},$$

where $0 \leq \rho_Z < 1$, Z is the steady state value of Z_t , and $v_{Z,t} \sim N(0, \sigma_Z^2)$.

Aggregate output, y_t , is a Dixit and Stiglitz (1977) continuum of differentiated products:

$$y_t = \left[\int_0^1 (y_{f,t})^{\varepsilon_p / (\varepsilon_p - 1)} df \right]^{(\varepsilon_p - 1) / \varepsilon_p},$$

where $-\varepsilon_p$ is the price elasticity of demand for good f . Cost minimization by households yields the demand equation for firm f 's good:

$$y_{f,t} = \left(\frac{P_{f,t}}{P_t} \right)^{-\varepsilon_p} y_t,$$

where $P_{f,t}$ is the price charged by firm f and P_t is a nonlinear price index:

$$P_t = \left[\int_0^1 (P_{f,t})^{1 - \varepsilon_p} df \right]^{1 / (1 - \varepsilon_p)}.$$

Every period, firm f utilizes the combination of labor and capital that minimizes its production costs, $w_t n_{f,t} + q_t k_{f,t}$, given the production function. The first-order conditions from firm f 's cost minimization yield the following factor demand equations:

$$q_t = \psi_t \alpha Z_t (n_{f,t} / k_{f,t})^{(1-\alpha)}$$

$$W_t / P_t = \psi_t (1 - \alpha) Z_t (k_{f,t} / n_{f,t})^\alpha,$$

where ψ_t is the Lagrange multiplier on the cost minimization problem and is interpreted as the real marginal cost of producing an additional unit of output. Furthermore, ψ_t is identical for all firms because every firm pays the same per unit capital and labor costs and has an equal measure of productivity, Z_t .

Firm f also determines each period whether or not the price, $P_{f,t}$, for its product, $y_{f,t}$, can be adjusted. Using the Calvo (1983) model of random adjustment, the probability that firm f can set a new price, P_t^* , is η_p , and the probability it can only adjust its price by the steady state inflation rate, π , is $(1 - \eta_p)$. Prices in this specification become perfectly flexible when η_p is set equal to 1. When a firm can set a new price, it selects a price that maximizes the discounted

value of its expected current and future profits subject to its factor demand and product demand equations:

$$P_t^* = \left(\frac{\varepsilon_p}{\varepsilon_p - 1} \right) \frac{E_t \left[\sum_{i=0}^{\infty} \beta^i \lambda_{t+i} \pi^i (1 - \eta_p)^i (P_{t+i} \pi^{-i})^{1+\varepsilon_p} \psi_{t+i} y_{t+i} \right]}{E_t \left[\sum_{i=0}^{\infty} \beta^i \lambda_{t+i} \pi^i (1 - \eta_p)^i (P_{t+i} \pi^{-i})^{\varepsilon_p} y_{t+i} \right]},$$

where $\beta^i \lambda_{t+i} \pi^i$ is the households' real value in period t of an additional unit of profits in period $t+i$, and $(1 - \eta_p)^i$ is the probability that the firm will not have an opportunity to set a new price in the subsequent i periods.

The Monetary Authority: Monetary policy operates with an interest rate rule.

Specifically, the monetary authority utilizes a generalized Taylor (1980) rule. The policy rule is defined by the following equations:

$$\ln(R_t / R) = \ln(\pi_t^* / \pi) + \theta_\pi \ln(\pi_t / \pi_t^*) + \theta_{dW} \ln(dW_t / dW_t^*) + \theta_P \ln(P_t / P) + \varepsilon_{R,t},$$

where π_t^* is the target inflation rate, dW_t is the nominal wage inflation rate, dW_t^* is the nominal wage inflation target, and $\varepsilon_{R,t}$ is a transitory monetary policy shock in which $\varepsilon_{R,t} = \rho_R \varepsilon_{R,t-1} + v_{R,t}$, $v_{R,t} \sim N(0, \sigma_R^2)$. Variables without time subscripts are steady state values. The steady state price inflation is equal to the steady state wage inflation because there is no trend in the real wage.

Whether the central bank has a target for price inflation or wage inflation, we assume a common functional form for the target setting process, so that we limit the discussion to the inflation target setting process. The target follows a common stochastic AR(1) process such that:

$$\ln(\pi_t^* / \pi) = \rho_\pi \ln(\pi_{t-1}^* / \pi) + v_{\pi,t},$$

where $v_{\pi,t} \sim N(0, \sigma_\pi^2)$. Assuming a common stochastic process for the price and wage inflation targets allows us to model policy uncertainty in a symmetric manner.

The target shocks and the transitory monetary policy shocks have similar effects on the nominal interest rate, except for the differences in their persistence. The target shock is to the long-run inflation objective, while the transitory shock is to the short-run liquidity position. The monetary authority in the model has a credible long-run inflation target equal to the steady state inflation rate, but the actual target rate may deviate from the steady state for an extended period.

In our model, the monetary authority has full credibility, which enables agents to distinguish between persistent shocks to the inflation target and temporary shocks to the liquidity position. That assumption is clearly realistic for cases such as the Fed's short-run responses to the 1987 stock market crash and the September 11 attacks. The absence of an explicit inflation target in the U.S., however, likely causes some confusion between those two shocks, especially in the Fed's reaction to news about the state of the economy.

III. Calibrating the Model

Most of the parameter calibrations we use are taken from characteristics of the U.S. data and/or have been widely used in the literature. In the utility function, the value of σ_1 is set at 1/3 implying that the elasticity of the labor supply with respect to the real wage is equal to 3. The value of σ_2 is set at 1/2, implying that the interest elasticity of money demand is equal to $-1/2$. The steady state labor share is 0.3 and the discount factor is 0.99. The capital share of output is set to 0.33 and the capital stock depreciates at 2.5 percent per quarter. The average and marginal capital adjustment costs around the steady state are zero (i.e., $\phi(\cdot) = i/k$ and $\phi'(\cdot) = 1$). The elasticity of the investment-to-capital ratio with respect to Tobin's q , $\chi = [(i/k)\phi''(\cdot)/\phi'(\cdot)]^{-1}$, is set to 5.

Large autocorrelation coefficients for the technology and preference shocks ($\rho_z = 0.95$ and $\rho_a = 0.90$) imply a high level of persistence. The standard deviation of the technology shock, σ_z , is set equal to 0.005 which is consistent with the lower volatility of output observed since 1984. The standard deviation of the preference shock, σ_a , is set equal to 0.01, which is consistent with Ireland (2005) who estimates that the preference shock is twice as large (in standard deviation) as the technology shock.

The parameters determining the effect of nominal rigidities are consistent with previous studies by Rotemberg and Woodford (1992), Erceg, Henderson, and Levin (2000), Keen (2004), Christiano, Eichenbaum, and Evans (2005), Ireland (2005), and Levin et al. (2005). The price elasticity of demand is set equal to 6, implying a steady state markup of 20 percent. This assumption is consistent with Rotemberg and Woodford (1992) and Christiano, Eichenbaum, and Evans (2005). We set the probability of price adjustment equal to 1 for the flexible price case and equal to 0.25 for the sticky price case. For the sticky price case, this parameter value implies that firms change prices on average once a year. The wage elasticity of labor demand is also set equal to 6, implying a steady state markup of 20 percent. We follow Levin et al. (2005) in setting a 20 percent markup in both the goods and labor markets. Christiano, Eichenbaum, and Evans (2005), on the other hand, estimate a much smaller wage markup. The probability of price adjustment is set equal to 1 for the flexible wage case and equal to 0.25 for the sticky wage case.

In our view, there are two important sources of uncertainty in U.S. policymaking that correspond to liquidity and inflation target shocks. We calibrate the liquidity shock to follow an AR(1) process with a first-order autocorrelation coefficient of 0.3 and a standard deviation of 0.002. This uncertainty may be due to the Fed's practice of making discrete changes in the interest rate. That practice causes a stochastic difference between the model's implied target and

the actual target. Dueker (2000), in a study of the prime rate, used a dynamic ordered probit model to estimate the spread between the banking system's desired prime rate and the actual prime rate in a world where changes are discrete. Using data from 1974-1999, Dueker estimates that the spread follows a first-order AR(1) process with an autocorrelation coefficient equal to 0.37 and a standard deviation of 26 basis points. Since the prime rate has been closely linked to the Fed funds rate, the difference between the prime rate and this latent variable should be a good proxy for the error induced into policy by the FOMC's practice of making discrete policy changes.

In recent years, FOMC members have stated inflation target preferences ranging from 1 to 3 percent. The lack of an explicit target suggests that the target inflation rate is stochastic. We set the steady state annual inflation rate at 2 percent and assume that a shock to the target inflation rate has a first-order autocorrelation coefficient equal to 0.95 and a quarterly standard deviation of 0.125 percent. Under that specification, a 95 percent confidence interval approximates an informal annual target range of 0.5 to 3.5 percent in the flexible price model. The specification represents an assumption about the degree of credibility that the central bank has for its inflation target.

IV. Evaluating Monetary Policy

Price and wage inflation targeting rules are evaluated in three alternative models—a sticky price model, a sticky wage model, and one that combines the results from those two with results from a flexible price and wage model. This third model represents a world in which the structure is consistently changing. The flexible model, sticky price model, and the sticky wage model represent three different states in our uncertain model. All three models converge to a

common steady state. The probability of remaining in the same model, regardless of the particular model, is 80 percent, while the probability of switching to one of the other two models is 10 percent each.²

While we are not advocating that the economy switches between different models, our specification of the uncertain model has some valuable attributes. First, this is one way to model the inherent uncertainty that exists about the true structure of the U.S. economy. Second, the uncertain model is an alternative method to average the results from the flexible, sticky price, and sticky wage models. Third, the specification eliminates the Calvo (1983) feature that causes a small fraction of firms or households to go an extremely long period between price or wage adjustment opportunities. For example, when the economy switches away from the sticky price (wage) model, all the firms (households) adjust to the equilibrium price (wage). That feature prevents agents from deviating too far from equilibrium when using the Calvo (1983) specification of price or wage stickiness.

Optimal Policy with No Policy Shocks. Levin et al. (2005) maintain that policy shocks to the inflation target or the liquidity position are not beneficial and, as a result, the monetary authority eliminates them when conducting optimal policy. Beginning with that assumption, we set the variances of the policy shocks to zero. Our three models are examined with strict price inflation and strict wage inflation targeting rules, where the weights on price inflation and wage inflation range from 1.1 to 5. Our measure of welfare is to minimize the standard deviation of the output gap, defined here as the deviation of output from its level in the flexible model. This criterion is based on Kim and Henderson's (2005) finding that the optimal monetary policy replicates the output path from the flexible price and wage equilibrium. To determine the

² Firms and households do not factor in the probability that the economy may switch between models when setting prices or wages, respectively.

standard deviation of the output gap, we perform 500 simulations on a sample set of 260 quarters of data where the first 100 quarters are discarded to randomize the initial conditions.

The top two panels in Figure 1 show the volatility of the output gap as the weight on the price or wage inflation target changes in our three models without policy shocks. If the monetary authority knows the form of nominal rigidity, the optimal monetary policy is to adopt a price inflation target when prices are sticky and a wage inflation target when wages are sticky. In the sticky price case, a weight on price inflation, θ_π , at or above 2 makes the variation in the output gap close to zero. In the sticky wage case, a weight on wage inflation, θ_{dw} , of 3 or more reduces the output gap variability to less than 0.2 percent.³

If the monetary authority mistakenly targets the wrong variable, the variability in the output gap is considerably higher. The top left-hand panel of Figure 1 shows that the standard deviation of the output gap rises from nearly zero in the sticky price model to around 1 percent in the sticky wage model when the target of policy is price inflation. The poor performance of the sticky wage model under a strict price inflation target is documented in Erceg, Henderson, and Levin (2000). The welfare loss is substantially less when the monetary authority targets wage inflation. The top right-hand panel of Figure 1 shows that the standard deviation of the output gap is less than 0.5 percent if the monetary authority chooses a wage inflation target in a sticky price economy.

The top two panels of Figure 1 also display the volatility of the output gap in our uncertain model. For that model, the optimal monetary policy is to target the wage inflation rate with a coefficient of 3 or higher. To the extent that sticky wages are an important feature of

³ We also experimented with an output term in the model (the central bank cannot observe the output gap). In general, the optimal weight on output is zero if the reaction coefficient on price or wage inflation is 3 or more.

macro dynamics, our results reinforce the well known finding that good monetary policy targets wage inflation.

Optimal Policy with Policy Shocks. Our previous investigation is repeated with the assumption that both inflation target shocks and liquidity shocks are present in the economy. The absence of a numerical inflation objective creates uncertainty about the Fed's inflation target.⁴ Gurkaynak, Sack, and Swanson (2003) show that the inflation premium in forward interest rates responds significantly to macroeconomic news, which they attribute to the absence of an explicit inflation target. Using a learning model, Orphanides and Williams (2005) show that uncertainty about the inflation objective can lead to sizable fluctuations in the long-term inflation outcome. Hence, inflation target shocks are the unintentional consequence of having a vague inflation objective. Liquidity shocks are also inadvertently introduced into the U.S. economy by the FOMC's practice of adjusting the federal funds rate in 25 basis point increments.

The bottom two panels of Figure 1 replicate the experiments in the top two panels but with policy shocks. The relative ranking of the policies is identical to the case without policy shocks. That is, an economy with price stickiness prefers a strict price inflation targeting rule and an economy with wage stickiness favors a wage inflation targeting rule. Comparing the top-row with the bottom-row also reveals that the introduction of policy shocks generates additional output gap variability when the monetary authority implements the optimal monetary policy rule. In a sticky price economy, the standard deviation of the output gap increases from near zero to 0.3 percent when the weight on the price inflation target is 2 or more. Similarly, the standard deviation of the output gap rises from about 0.1 percent to 0.5 percent in a sticky wage model when the coefficient on wage inflation is 3 or higher. If, on the other hand, the monetary

⁴ See Ireland (2005) for a historical analysis of the Fed's unobserved inflation objective. Also, see Kozicki and Tinsley (2005) for estimates of these policy shocks.

authority picks the wrong target (i.e., a price inflation target in a sticky wage model or a wage inflation target in a sticky price model), the variability of the output gap hardly changes when policy shocks are included in the model.

The Term Structure of Inflation Expectations. Monetary policymakers are concerned about the consequences of their policy actions on inflation expectations embedded in the longer-term bond market. Although our model does not contain the features needed to examine fully this issue, we report the impact of alternative policy rules on the volatility of inflation over a term structure ranging from one to ten years. We do not consider the real term-structure effects and the covariance between inflation and real returns. In our analysis, the coefficient on the price inflation target or wage inflation target is set to 3. By starting at the steady state and shocking the exogenous variables, we simulate 10 years of data over 500 times to obtain a distribution of inflation rates over 1- through 10- year horizons. This experiment enables us to address the question, “How does the monetary policy rule affect the distribution of future inflation over the next 10 years?”

Our results in Figure 2 show that inflation uncertainty differs considerably between policy rules, but the results do not depend on the type of nominal rigidity except at the shortest horizons. In the top row, we see that, in the absence of policy shocks, price inflation targeting always reduces expected inflation uncertainty better than wage inflation targeting. The three models generate nearly identical degrees of expected inflation uncertainty under the strict price inflation-targeting rule. For the strict wage targeting rule, the sticky price model generates much less uncertainty than the other two models on the short end of the yield curve, but the degree of uncertainty produced by the three models declines and converges as the time horizon increases.

The bottom row of Figure 2 shows that policy shocks are an important source of uncertainty about inflation. The standard deviation of inflation at longer horizons is about 0.7 to 0.8 percentage points higher with policy shocks. Again, strict price inflation targeting does better than strict wage inflation targeting, but the differences are small for horizons longer than one year.

Price Path Targeting. Several authors beginning with Svensson (1999) have shown that price path targeting by the monetary authority improves the tradeoff between output and inflation variability. The term price path targeting rather than price level targeting recognizes the possibility that the price target can grow over time. The critical point is that the price level follows a deterministic, not a stochastic, trend. Our price path target is equivalent to imposing a long-run inflation target on the monetary policy rule.

Figure 3 documents the degree of expected inflation uncertainty when a small weight ($\theta_p = 0.2$) is combined with a sizable weight on the price ($\theta_\pi = 3$) or wage ($\theta_{dw} = 3$) inflation target. The left and right columns in Figure 3 report the results using a price inflation and wage inflation target, respectively. From top to bottom, the rows of Figure 3 report the results for the sticky price model, the sticky wage model, and the uncertain model. As noted in Figure 2, the broad pattern of results for inflation uncertainty does not depend on the source of nominal rigidity. By adopting a price path target, the policymaker virtually eliminates the uncertainty about future inflation that is induced by the policy shocks.

While including a price path target decreases long-run inflation uncertainty, we need to determine its impact on the variability of the output gap. Figure 4 compares the output gap volatility under both policy rules with and without a price path target. Our computation procedure is identical to that in Figure 1 except that strict price and wage inflation targeting rules

are compared to ones with some weight (0.2) on the price path. In most cases, the inclusion of a price path target with a large coefficient on price or wage inflation has a very small effect on the variability of the output gap. The exception is the sticky wage model when the coefficient on a wage inflation target is sizable. When θ_{dw} is 3, the output gap variability for the sticky wage model is about 0.2 percentage points higher, but the volatility of the 10-year ahead inflation forecast is 0.7 percentage points lower. With sticky prices, the addition of a small weight on the price path has almost no effect on the output gap. If, however, the weight on the price or wage inflation target is near 1, placing some weight on the price path actually reduces both inflation and output volatility.

Conclusion

The optimal monetary policy in New Keynesian models depends on the source of nominal rigidity. When prices are sticky, it is optimal to stabilize price inflation, whereas, it is optimal to stabilize wage inflation when wages are sticky. This article shows that, in both cases, the optimal policy generates a relatively large amount of uncertainty about long-run inflation.

By placing some weight on a deterministic price path, a central bank can reduce the long-run inflation uncertainty inherent in the optimal policies. In the sticky price case, this policy reduces long-run inflation uncertainty without any measurable increase in the variability of the output gap. When wages are sticky and the central bank targets wage inflation, adding a price path reduces inflation uncertainty, but raises the variance of the output gap. Specifically, inflation uncertainty at the ten-year horizon falls by 0.7 percentage points while the output gap rises only by about 0.2 percentage points.

Our results indicate that there are two important topics for future research. First, we need a better understanding on why long-run inflation risk matters for social welfare. Second, we need to reconcile the disconnect between New Keynesian theory and central bank practice. That is, theory implies that wage inflation targeting dominates price inflation targeting but central banks prefer price inflation targets over wage inflation targets.

References

- Ang, Andrew, Sen Dong, and Monica Piazzesi. "No-Arbitrage Taylor Rules," Manuscript presented at the SED meetings in Budapest, June 2005.
- Balke, Nathan S. and Kenneth M. Emery. "The Algebra of Price Stability," *Journal of Macroeconomics* (1994), 77-97.
- Bansal, Ravi and Amir Yaron. "Risks for the Long Run: A Potential Resolution of Asset Pricing Puzzles," *Journal of Finance* 59 (2004), 1481-1509.
- Brainard, William C. "Uncertainty and the Effectiveness of Policy," *The American Economic Review* 57 (1967), 411-25.
- Brock, William A., Steven N. Durlauf, and Kenneth D. West. "Policy Evaluation in Uncertain Economic Environments," *Brookings Papers on Economic Activity* 2003(1), 235-323.
- Campbell, John Y., and Luis M. Viceira. "Who Should Buy Long-Term Bonds?" *American Economic Review* 91 (March 2001), 99-127.
- Canzoneri, Matthew B., Robert E. Cumby, and Behzad T. Diba. "Price and Wage Inflation Targeting: Variations on a Theme by Erceg, Henderson, and Levin," presented at the Conference on "Models and Monetary Policy: Research in the Tradition of Dale Henderson, Richard Porter, and Peter Tinsley," March 26-27, Federal Reserve Board.
- Canzoneri, Matthew B., Dale Henderson, and Kenneth Rogoff. "The Information Content of the Interest Rate and Optimal Monetary Policy," *Quarterly Journal of Economics* 98 (1983), 545-566.
- Christiano, Lawrence J., Martin Eichenbaum, and Charles L. Evans. "Nominal Rigidities and the Dynamic Effects of a Shock to Monetary Policy," *Journal of Political Economy* 113 (February 2005), 1-45.
- Christiano, Lawrence J. and Christopher J. Gust. "Robustness of Simple Monetary Policy Rules under Model Uncertainty: Comment," in John B. Taylor, ed., *Monetary Policy Rules*, Chicago: Chicago University Press (1999), 299-316.
- Cogley, Timothy and Thomas J. Sargent. "The Conquest of U.S. Inflation: Learning and Robustness to Model Uncertainty," manuscript, New York University, October 2004.
- Dennis, Richard. "Uncertainty and Monetary Policy," *FRBSF Economic Letter*, November 30, 2005.
- Dittmar, Robert D., William T. Gavin, and Finn E. Kydland. "Price-Level Uncertainty and Inflation Targeting," *Federal Reserve Bank of St. Louis Review* 81 (July/August 1999), 23-33.

- Dixit, Avinash and Joseph Stiglitz. "Monopolistic Competition and Optimum Product Diversity," *American Economic Review* 57 (1977), 297–308.
- Dueker, Michael J. "Are Prime Rate Changes Asymmetric?" Federal Reserve Bank of St. Louis *Review* 82 (September/October 2000), 33-40.
- Epstein, Lawrence G. and Stanley Zin. "Substitution, Risk Aversion and the Temporal Behavior of Consumption and Asset Returns: A Theoretical Framework," *Econometrica* 57 (July 1989), 937-69.
- Erceg, Christopher, Dale W. Henderson, and Andrew Levin. "Optimal Monetary Policy with Staggered Wage and Price Contracts," *Journal of Monetary Economics* 46 (2000), 281–313.
- Gavin, William T., Benjamin D. Keen, and Michael R. Pakko. "The Monetary Instrument Matters," Federal Reserve Bank of St. Louis *Review*-87 (September/October 2005), 633-658.
- Gertler, Mark. "Performance of Operational Policy Rules in an Estimated Semiclassical Structural Model: Comment," in John B. Taylor, ed., *Monetary Policy Rules*, 46-54. Chicago: Chicago University Press (1999).
- Greenspan, Alan. "Opening Remarks," in *Monetary Policy and Uncertainty: Adapting to a Changing Economy*, A Symposium Sponsored by the Federal Reserve Bank of Kansas City (August 28-30, 2003), 1-7.
- Hansen, Lars and Thomas Sargent. "Acknowledging Misspecification in Macroeconomic Theory," *Review of Economic Dynamics* 4 (2002), 519-35.
- Hansen, Lars and Thomas Sargent. "Certainty Equivalence' and 'Model Uncertainty,'" Paper presented at conference on *Models and Monetary Policy: Research in the Tradition of Dale Henderson, Richard Porter, and Peter Tinsley*, March 27-28, 2004.
- Hayashi, Fumio. "Tobin's Marginal and Average q: A Neoclassical Interpretation," *Econometrica* 50 (1982), 213-224.
- Ireland, Peter N. "Changes in the Federal Reserve's Inflation Target: Causes and Consequences," manuscript Boston College, January 2005.
- Keen, Benjamin D. "In Search of the Liquidity Effect in a Modern Monetary Model," *Journal of Monetary Economics* 51 (2004), 1467-1494.
- Kim, Jinill and Dale W. Henderson. "Inflation Targeting and Nominal Income Growth Targeting: When and Why are They Suboptimal?" *Journal of Monetary Economics* 52 (2005), 1463-1496.

- King, Robert G. and Alexander L. Wolman. "What Should the Monetary Authority Do When Prices Are Sticky?" in John B. Taylor, ed., *Monetary Policy Rules*, Chicago: Chicago University Press (1999), 203-246.
- Kozicki, Sharon and Peter A. Tinsley. "Permanent and Transitory Policy Shocks in an Empirical Macro Model with Asymmetric Information," *Journal of Economic Dynamics and Control* 29 (2005), 1985-2015.
- Levin, Andrew T., Alexei Onatski, John C. Williams, and Joah Williams. "Monetary Policy under Uncertainty in Micro-Founded Macroeconometric Models," NBER Working Paper 11523, July 2005.
- Levin, Andrew T. and John C. Williams. "Robustness Monetary Policy in Competing Reference Models," *Journal of Monetary Economics* 50 (2003), 945-975.
- Levin, Andrew T., Volker Wieland, and John C. Williams. "The Performance of Forecast-Based Monetary Policy Rules Under Model Uncertainty," *American Economic Review* 93 (2003), 622-45.
- Levin, Andrew T., Volker Wieland, and John C. Williams. "Robustness of Simple Monetary Policy Rules under Model Uncertainty," in John B. Taylor, ed., *Monetary Policy Rules*, Chicago: Chicago University Press (1999), 263-299.
- McCallum, Bennett T. "Robustness Properties of a Rule for Monetary Policy," *Carnegie-Rochester Conference Series on Public Policy*, 29 (1988), 173-203.
- McCallum, Bennett T. and Edward Nelson. "Performance of Operational Policy Rules in an Estimated Semiclassical Structural Model," in John B. Taylor, ed., *Monetary Policy Rules*, Chicago: Chicago University Press (1999), 15-45.
- Nessen, Marianne, and David Vestin. "Average Inflation Targeting," *Journal of Money, Credit and Banking* 37 (2005). See <http://www.ohiostatepress.org/> to view forthcoming articles.
- Onatski, Alexei and James H. Stock. "Robust Monetary Policy Under Model Uncertainty in a Small Model of the U.S. Economy," *Macroeconomic Dynamics* 6 (2002), 85-110.
- Orphanides, Athanasios and John C. Williams. "Robust Monetary Policy Rules with Unknown Natural Rates," *Brookings Papers on Economic Activity*, 2002, Issue 2, 63-118.
- Orphanides, Athanasios and John C. Williams. "Inflation Scares and Forecast-Based Monetary Policy," *Review of Economic Dynamics* 8 (2005), 498-527.
- Reifschneider, David and John C. Williams. "Three Lessons for Monetary Policy in a Low-Inflation Era," *Journal of Money, Credit and Banking* 32 (2000), 936-66.

- Reis, Riccardo. "The Time-Series Properties of Aggregate Consumption: Implications for the Cost of Fluctuations," Manuscript, Princeton University, April 2005.
- Rotemberg, Julio and Michael Woodford. "Oligopolistic Pricing and the Effects of Aggregate Demand on Economic Activity," *Journal of Political Economy* 37 (1992), 505-533.
- Sargent, Thomas J. and Timothy Cogley. "The Conquest of U.S. Inflation: Learning and Robustness to Model Uncertainty," Working Paper UC Davis and New York University (October 2004).
- Schmitt-Grohé, Stephanie and Martín Uribe. "Optimal Fiscal and Monetary Policy in a Medium-Scale Macroeconomic Model: Expanded Version," NBER Working Paper 11417, June 2005.
- Stock, James H. and Mark W. Watson. "Forecasting Output and Inflation: The Role of Asset Prices," *Journal of Economic Literature* 41 (2003), 788-829.
- Stock, James H. and Mark Watson. "Evidence on Structural Instability in Macroeconomic Time Series Relations," *Journal of Business and Economic Statistics*. 14 (1996), 11-30.
- Svensson, Lars E. O. "Price-Level Targeting vs. Inflation Targeting: A Free Lunch?" *Journal of Money, Credit and Banking* 31 (1999), 277-95.
- Taylor, John B., Ed. *Monetary Policy Rules* NBER, The University of Chicago Press, 1999.
- Tetlow, Robert J. and Brian Ironside. "Real-Time Model Uncertainty in the United States: The Fed from 1996-2003," presented at the "International Research Forum on Monetary Policy: Third Conference." The May 31, 2005 version is at <http://www.roberttetlow.com>.
- Tetlow, Robert J. and P.von zur Muehlen, "Robust monetary policy with misspecified models: does model uncertainty always call for attenuated policy?" *Journal of Economic Dynamics and Control* 25 (2001), 911-949.
- Williams, John. "Simple Rules for Monetary Policy," Federal Reserve Bank of San Francisco *Review*, (2003), 1-12.
- Woodford, Michael. *Interest and Prices: Foundations of a Theory of Monetary Policy*, Princeton University Press, 2003.

Figure 1: Optimal Monetary Policy

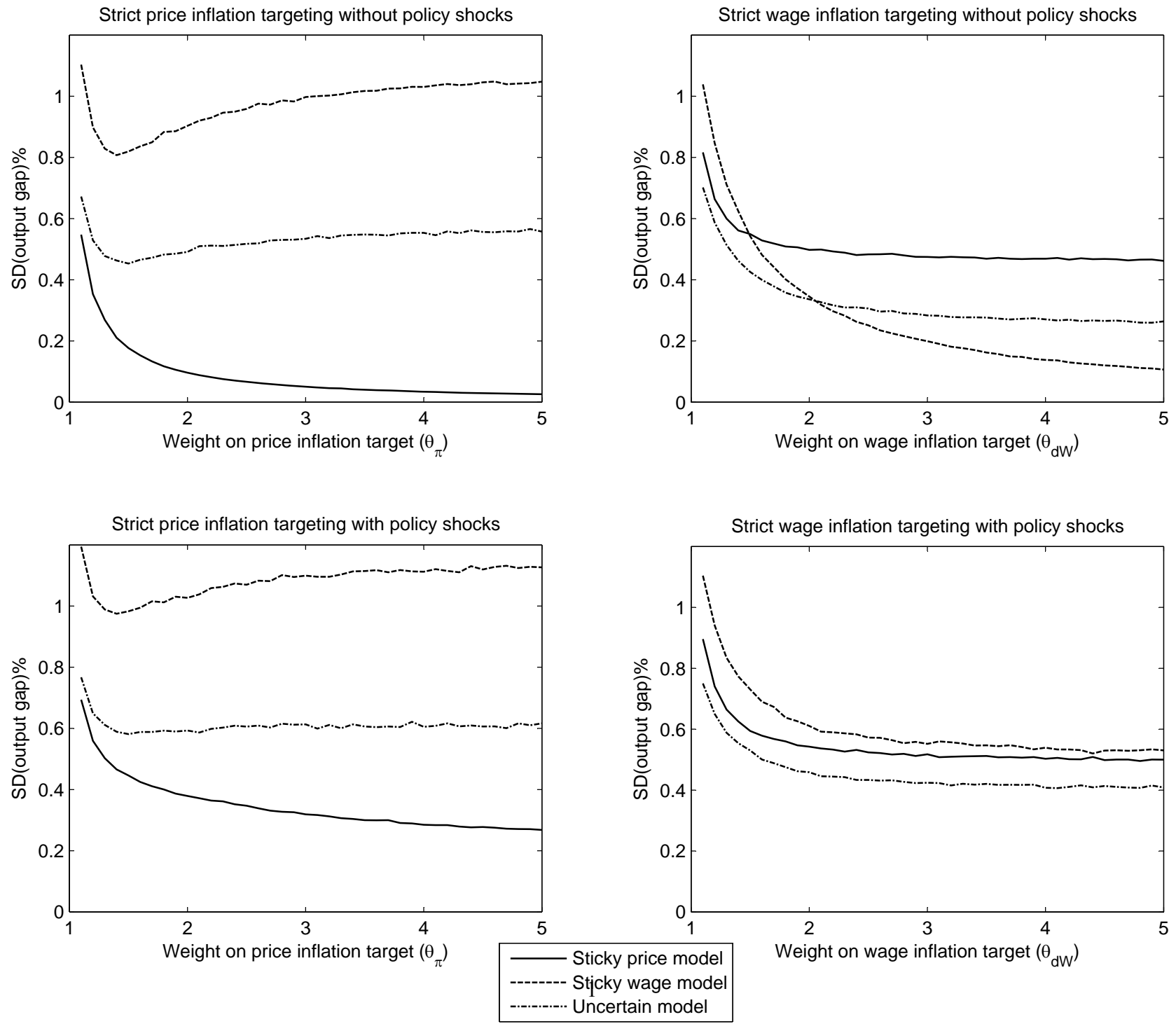
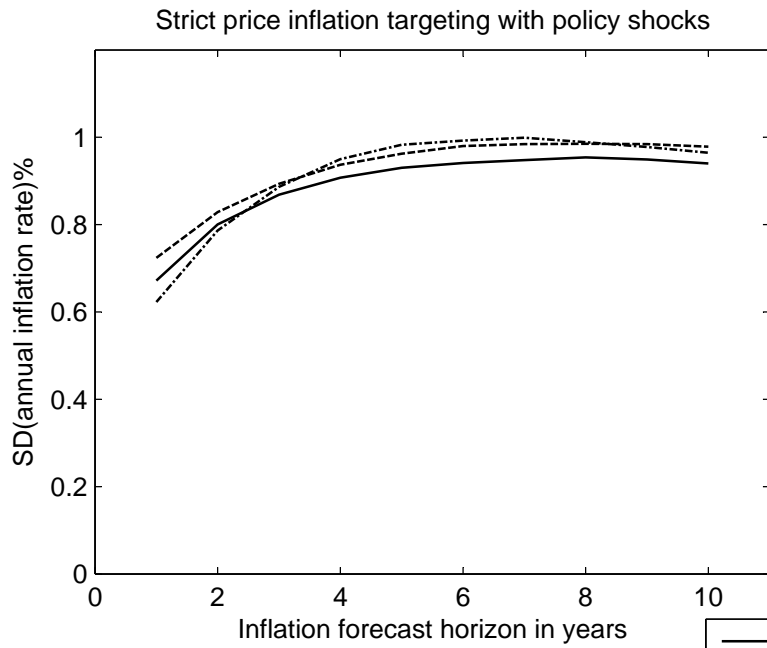
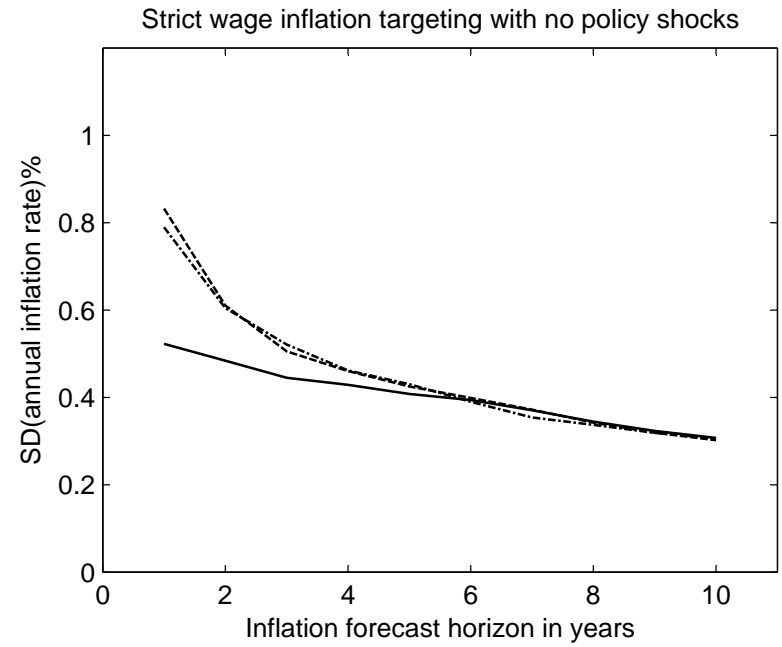
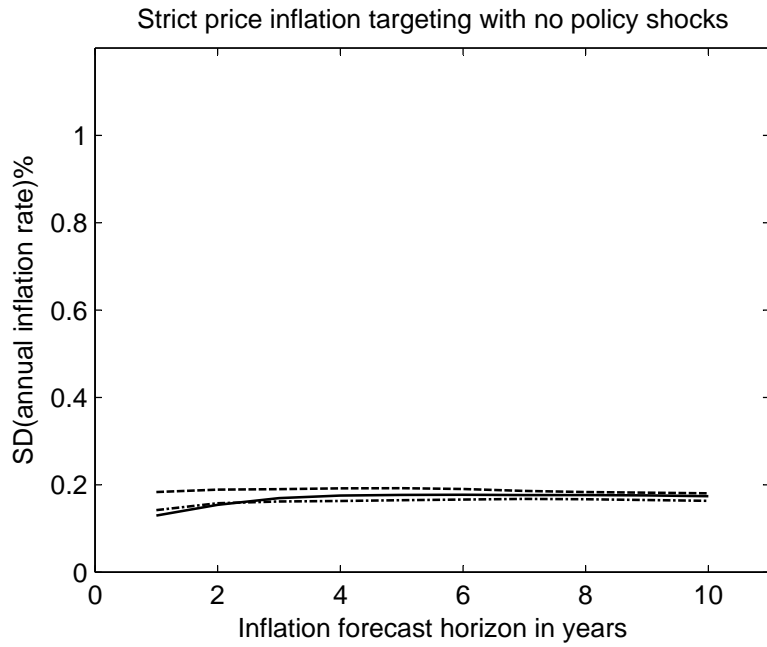


Figure 2: Long-Run Inflation Uncertainty



— Sticky price model
- - - Sticky wage model
- · - · - Uncertain model

Figure 3: Long-Run Inflation Uncertainty with Policy Shocks

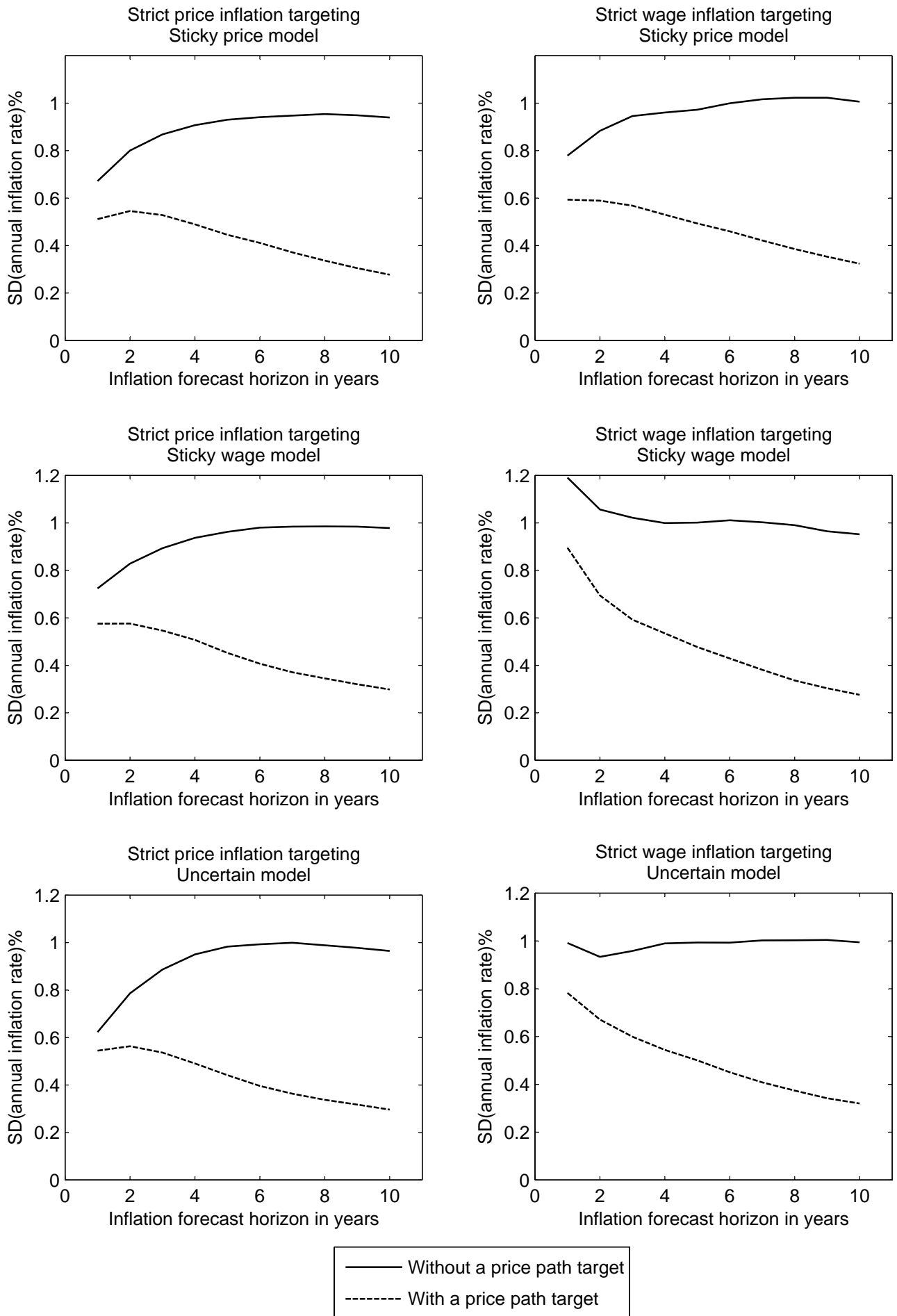


Figure 4: Optimal Monetary Policy and a Price Path Target

