Price and Wage Inflation Targeting: Variations on a Theme by Erceg, Henderson and Levin*

by

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I. INTRODUCTION

Inflation targeting is currently in vogue; some twenty central banks have now adopted it as a framework for implementing monetary policy.[1] King and Wolman (1999) showed that strict price inflation targeting (that is, fixing the price level) achieves the constrained optimum in a model with price inertia, thereby providing a rationale for inflation targeting within the class of New Neoclassical Synthesis (NNS) models.[2] However, Erceg, Henderson and Levin (2000) (EHL) showed that strict inflation targeting is no longer optimal when wage inertia is added to the model; the central bank should also respond to movements in the nominal wage (or the output gap). In fact, when wage inertia is the only nominal inertia in the model, the King and Wolman result is completely turned around; the constrained optimum can be achieved by strict wage inflation targeting (that is, fixing the nominal wage level).

The intuition for such results is not new. In an earlier class of models with fixed wages and flexible prices, the optimal monetary policy moved quantities so as to make nominal wage movements unnecessary. In the language of Canzoneri, Henderson and Rogoff (1983), monetary policy made wage flexibility "redundant"; it saved wage setters the costs (whatever they are) of indexing wages to current information. In the Canzoneri, Henderson and Rogoff model, monetary policy accomplished this by making the notional wage equal to the preset wage; in NNS models, where some firms have flexible wages while others have preset wages, monetary policy can accomplish

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[1]Truman (2003) provides the current list (see page 1), and a discussion of inflation targeting in practice. The literature on inflation targeting is vast; interesting discussions include Faust and Henderson (2003) and Bernanke et al. (1999).

[2]The New Neoclassical Synthesis adds nominal inertia to the Real Business Cycle model. Goodfriend and King (1997) outlined the synthesis, and gave it the name. Woodford (2003) provides a masterful introduction to this class of models. The NNS was quickly adopted as a framework for monetary policy evaluation, and a large literature has ensued.

this by fixing the aggregate wage level. Similarly, in NNS models with sticky prices and flexible wages, monetary policy can make price flexibility “redundant” by fixing the aggregate price level. In models with both wage and price inertia, monetary policy has to trade off wage and price stability.

It is natural to think of monetary policy as regulating something nominal. The aggregate price level (and price inflation targeting) has received much attention. The aggregate wage rate (and wage inflation targeting) is an obvious alternative, but it has received almost no attention. In this paper, we compare price and wage inflation targeting rules in six different models with price and wage inertia. Model 1 is quite similar to the EHL model. It has monopolistic price and wage setters, and Calvo (1983) style price and wage ‘contracts’; it has subsidies that eliminate the distortions due to monopolistic competition; it has a fixed aggregate capital stock, but capital is mobile across firms; and productivity shocks are the only source of uncertainty. Model 2 is like Model 1, except there are no subsidies. The distortions due to monopolistic competition are large in our calibrated model; steady state consumption is 12% higher with the subsidies. Comparing Models 1 and 2, we can see whether these distortions interact with the price and wage inertia in a way that is significant for monetary policy.

The next set of models was selected to see whether the way in which capital is modeled is important for monetary policy evaluation. Model 3 is like Model 2, except households are allowed to accumulate capital over time.[3] Traditional analyses of aggregate demand management often abstracted from capital formation; capital accumulation was thought to be about long run growth, while the stabilization problem was concerned with fluctuations about the growth path. However, it is

[3]Model 3 is similar to the model of Collard and Dellas (2003), but with Calvo contracts for wages (in addition to prices).

clear that the option of accumulating capital gives a utility maximizing household one more way of responding to a productivity shock; allowing for capital accumulation may affect monetary policy evaluation in a significant way.

Model 4 is like Model 2, except capital is firm specific. The assumption of capital mobility is quite common in the literature.[4] However, as Woodford (2003, page 353) has noted, "... (the) assumption of a single economy wide rental market for capital is plainly unrealistic, and its consequences are far from trivial in the present context: It would imply that differences in the demand for goods that have their prices set at different times should result in instantaneous relocations of the economy's capital stock from lower demand to higher demand (firms), and this in turn has an important effect upon the degree to which marginal cost of supply should vary with the demand for a given good." There seems to be a wide spread perception among NNS modelers that firm specific capital might increase the costs of nominal inertia, affecting our analysis in a significant way.

Finally, Model 5 assumes that there is no capital at all. Production is linear in the labor input. This completes the set of models that compare different ways of modeling capital.

In all of the models considered above, productivity shocks are the only source of uncertainty.[5] The NNS framework grew out of the RBC paradigm, and it is not surprising that the early literature should have focused on productivity shocks. More recent work has added other shocks. To see whether our results for price and wage inflation targeting extend to more elaborate settings, we investigate one final model. Model 6 is like Model 3, except it adds habit formation

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[4]Part of the appeal of this assumption is its analytical tractability. It is currently beyond our ability to analyze capital accumulation in a model with firm specific capital.

[5]EHL modeled other shocks, but did not use them in their analysis of monetary policy.

to consumption decisions, a discount factor shock, and a fiscal spending shock. We will argue that our calibration of Model 6 captures many features of the U.S. economy.

It may be best to summarize our main results at the outset. We find that it is very important to model capital when examining the welfare effects of inflation targeting rules; omitting capital can alter the results in a significant way. However, it does not seem to matter much how capital is modeled; and in particular, making capital firm specific does not seem to have the big normative implications that some might have expected. With price inflation targeting (a rule that makes the interest rate respond just to price movements), there appears to be an optimal volatility of price inflation; in all of the models, really clamping down on the price level leads to welfare costs that are three or four times larger than necessary. The optimal level of volatility is of course model dependent. With wage inflation targeting (a rule that makes the interest rate respond just to wage movements), there does not appear to be an optimal volatility of wage inflation; the tighter the targeting rule the better. In this sense, a good wage inflation targeting rule is easier to describe, and more robust across models. Perhaps the most surprising result to come out of our analyses is that a tight form of wage inflation targeting appears to strongly dominate price inflation targeting. For example, in Model 6, a wage inflation targeting rule that brings price inflation volatility down to existing levels implies welfare costs of nominal inertia that are an order of magnitude lower than the equivalent price inflation targeting rule. Finally, EHL showed that a better rule would include elements of both price and wage inflation targeting, but we find that hybrid rules do not seem to do much better than a tight form wage inflation targeting.

The rest of the paper is organized as follows. Section II outlines Model 3, and explains how Models 1, 2, 4 and 5 can be derived from it; Model 6 is described later (in Section IV). Section III studies price inflation targeting and the modeling of capital using Models 1, 2, 3, 4 and 5. Section IV compares price and wage inflation targeting in all of the models. Section V concludes by discussing why wage inflation targeting does so well in our models, and assessing the implications for monetary policy and for NNS modeling generally.

II. An Outline of Models 1, 2, 3, 4, and 5

We begin with a description of Model 3, and its calibration. Like other NNS models, Model 3 is characterized by optimizing agents, monopolistic competition, and nominal inertia. It is similar to the EHL model, except we allow households to accumulate capital, and we solve the model by calculating second order approximations to both the model and the welfare function.[6] Model 3 is very closely related to the model in Canzoneri, Cumby and Diba (2004); so, our description can be brief.

2.1. Firms' price setting behavior –

There is a continuum of firms indexed by f on the unit interval. Each firm rents capital $K_{t-1}(f)$ at the rate R_t, hires a labor bundle $N_t(f)$ at the rate W_t, and produces a differentiated product

(1) $Y_t(f) = Z_t K_{t-1}(f)^{\nu} N_t(f)^{\nu-1}$,

where $0 < \nu < 1$, and Z_t is an economy wide productivity shock that follows an auto regressive process – $\log(Z_t) = \rho\log(Z_{t-1}) + \epsilon_{p,t}$. The firm's cost minimization problem implies

(2) $R_t/W_t = [\nu/(1-\nu)](N_t(f)/K_t(f))$,

and the firm's marginal cost can be expressed as

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[6]EHL employed the Linear-Quadratic approach pioneered by Julio Rotemberg and Michael Woodford; see Woodford (2003).

(3) $MC_t(f) = [\nu^{\nu}(1-\nu)^{(1-\nu)}]^{-1}R_t^{\nu}W_t^{1-\nu}/Z_t$.

The modeling of monopolistic competition is now standard.[7] A composite good

(4) $Y_t = [\int_0^1 Y_t(f)^{(\phi p-1)/\phi p}df]^{\phi p/(\phi p-1)}$, $\phi_p > 1$,

can be used as either a consumption good or capital. The constant elasticity aggregator, (4), reflects household preferences. The good's price, which can be interpreted as the aggregate price level, is given by

(5) $P_t = [\int_0^1 P_t(f)^{1-\phi p}df]^{1/(1-\phi p)}$,

and demand for the product of firm f is given by

(6) $Y_t^d(f) = (P_t /P_t(f))^{\phi p}Y_t$.

Following Calvo (1983), firms set prices in staggered 'contracts' of random duration. In any period t, each firm gets to announce a new price with probability (1-α); otherwise, the old contract, and its price, remains in effect.[8] The average duration of a price contract is $(1-\alpha)^{-1}$ quarters.

If firm f gets to announce a new contract in period t, it chooses a new price $P_t^*(f)$ to maximize the value of its profit stream over states of nature in which the new price is expected to hold:

(7) $E_t\sum_{j=t}^{\infty}(\alpha\beta)^{j-t}\lambda_j[S_pP_t^*(f)Y_j(f) - TC_j(f)]$,

where TC(f) is the firm's total cost, β is the households' discount factor, and λ_j is the households' marginal utility of nominal wealth (to be defined below). S_p is a price subsidy (when greater than one). The firm's first order condition is

(8) $P_t^* = (\mu_p/S_p)(PB_t/PA_t)$,

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[7]A fuller description is given by Canzoneri, Cumby and Diba (2003).

[8]We set steady state inflation equal to zero. But, our results would be the same if we let the contract price rise with a non-zero steady state rate of inflation; see EHL (2000).

where $\mu_p = \phi_p/(\phi_p - 1)$ is a monopoly markup factor, and

(9) $PB_t = E_t\sum_{j=t}^{\infty}(\alpha\beta)^{j-t}\lambda_j MC_j(f)P_j^{\phi p}Y_j = \alpha\beta E_t PB_{t+1} + \lambda_t MC_t(f)P_t^{\phi p}Y_t$

(10) $PA_t = E_t\sum_{j=t}^{\infty}(\alpha\beta)^{j-t}\lambda_j P_j^{\phi p}Y_j = \alpha\beta E_t PA_{t+1} + \lambda_t P_t^{\phi p}Y_t$

As $\alpha \rightarrow 0$, all firms reset their prices each period (the flexible price case), and $P_t^*(f) \rightarrow (\mu_p/S_p)MC_t(f)$. Since the markup is positive ($\mu_p > 1$), output will be inefficiently low in the flexible price solution. In Model 1, we set $S_p = \mu_p$ to eliminate this distortion; in the other models, $S_p = 1$.

2.2. Households' wage setting behavior and capital accumulation –

There is a continuum of households indexed by h on the unit interval. Each household supplies a differentiated labor service to all of the firms in the economy. The composite labor bundle

(11) $N_t = [\int_0^1 L_t(h)^{(\phi w-1)/\phi w}dh]^{\phi w/(\phi w-1)}, \ \phi_w > 1,$

reflects the firms' production technology. Cost minimization implies that the bundle's wage is

(12) $W_t = [\int_0^1 W_t(h)^{1-\phi w}dh]^{1/(1-\phi w)},$

and demand for the labor of household h is

(13) $L_t^d(h) = (W_t/W_t(h))^{\phi w}N_t.$

The utility of household h is

(14) $U_t(h) = E_t\sum_{\tau=t}^{\infty}\beta^{\tau-t}[\log(C_\tau(h)) - (1+\chi)^{-1}L_\tau(h)^{1+\chi}],$

where $C_t(h)$ is household consumption of the composite good, and the second term on the RHS of (14) reflects the household's disutility of work.[9] The household's budget constraint is

[9]The utility function (and budget constraint below) should also include a term in real money balances, but we follow much of the NNS literature in assuming that this term is negligible. An interest rate rule characterizes monetary policy, so there is no need to model money explicitly.

(15) $E_t[\Delta_{t,t+1}B_{t+1}(h)] + P_t[C_t(h) + I_t(h) + T_t] = B_t(h) + S_w W_t(h) L_t^d(h) + R_t K_{t-1}(h) + D_t(h)$

where the first term on the LHS is a portfolio of contingent claims; I_t is the household's investment in capital, T_t is a lump sum tax (used by the government to balance its budget constraint each period), and the last three terms on the RHS are the household's wage, rental and dividend income. S_w is a wage subsidy (when greater than one). The household's capital accumulation is governed by

(16) $K_t(h) = (1 - \delta)K_{t-1}(h) + I_t(h) - ½\psi[(I_t(h)/K_{t-1}(h)) - \delta]^2 K_{t-1}(h)$,

where δ is the depreciation rate, and the last term is the cost of adjusting the capital stock.

Household h maximizes utility, (14), subject to its budget constraint, (15), its labor demand curve, (13), and its capital accumulation constraint, (16). We begin with the wage setting decision. Following Calvo (1983), households set wages in staggered 'contracts' of random duration. In any period t, each household gets to announce a new wage with probability (1-ω); otherwise, the old contract, and its wage, remains in effect. The average duration of a wage contract is $(1-\omega)^{-1}$ quarters.

If household h gets to announce a new contract in period t, it chooses the new wage

(17) $W_t^{*1+\phi w\chi} = (\mu_w/S_w)(WB_t/WA_t)$,

where $\mu_w = \phi_w/(\phi_w-1)$ is a monopoly markup factor, and

(18) $WB_t = E_t\sum_{j=t}^{\infty}(\omega\beta)^{j-t}N_j^{1+\chi}W_j^{\phi w(1+\chi)} = \omega\beta E_t WB_{t+1} + N_t^{1+\chi}W_t^{\phi w(1+\chi)}$,

(19) $WA_t = E_t\sum_{j=t}^{\infty}(\omega\beta)^{j-t}\lambda_j N_j W_j^{\phi w} = \omega\beta E_t WA_{t+1} + \lambda_t N_t W_t^{\phi w}$,

where λ_j is the household's marginal utility of nominal wealth (to be defined below). As $\omega \to 0$, all households get to reset their wages each period (the flexible wage case), and $W_t^*(h) = (\mu_w/S_w)N_t^{\chi}/\lambda_t$; that is, the wage is a markup over the (dollar value of the) marginal disutility of work. Since the markup is positive ($\mu_w > 1$), the labor supplied will be inefficiently low in the flexible wage solution.

In Model 1, we set $S_w = \mu_w$ to eliminate this distortion; in the other models, $S_w = 1$. Note that $1/\chi$ is the Frisch (or constant λ_t) elasticity of labor supply.

When wages are sticky ($\omega > 0$), wage rates will generally differ across households, and firms will demand more labor from households charging lower wages. Our model is inherently one of heterogeneous agents, but complete contingent claims markets imply that all households have the same marginal utility of wealth, λ; this make households identical in terms of their consumption and investment decisions.[9] In equilibrium, aggregate consumption is equal to household consumption, $C_t = C_t(h)$; the same is true of the aggregate capital stock, $K_{t-1} = K_{t-1}(h)$. So, we can write the equilibrium versions of the households' first order conditions for consumption and investment in terms of aggregate values:

(20) $1/P_tC_t = \lambda_t$,

(21) $\beta E_t[\lambda_{t+1}/\lambda_t] = E_t[\Delta_{t,t+1}] = (1+i_t)^{-1}$

(22) $\lambda_t P_t = \xi_t - \xi_t\psi[(I_t/K_{t-1}) - \delta]$,

(23) $\xi_t = \beta E_t\{\lambda_{t+1}R_{t+1} + \xi_{t+1}[(1-\delta) - \frac{1}{2}\psi[(I_{t+1}/K_t) - \delta]^2 + \psi[(I_{t+1}/K_t) - \delta](I_{t+1}/K_t)\}$,

where λ_t and ξ_t are the Lagrangian multipliers for the households' budget and capital accumulation constraints, and i_t is the return on a 'risk free' bond.

2.3. The aggregate price and wage levels, aggregate employment and aggregate output –

The aggregate price level can be written as

(24) $P_t = [\int_0^1 P_t(f)^{1-\phi p}df]^{1/(1-\phi p)} = [\sum_{j=0}^{\infty} (1-\alpha)\alpha^j(P^*_{t-j}(f))^{1-\phi p}]^{1/(1-\phi p)}$,

since the law of large numbers implies that $(1-\alpha)\alpha^j$ is the fraction of firms that set their prices t-j periods ago, and have not gotten to reset them since. It is straightforward to show that

[9] See Canzoneri, Cumby and Diba (2004) for a fuller discussion of this.

(25) $P_t^{1-\phi p} = (1-\alpha)P_t^{*1-\phi p} + \alpha(P_{t-1})^{1-\phi p}$.

Similarly, the aggregate wage (defined by equation (12)) can be written as

(26) $W_t^{1-\phi w} = (1-\omega)W_t^{*1-\phi w} + \omega(W_{t-1})^{1-\phi w}$.

In Canzoneri, Cumby and Diba (2004), we showed that aggregate output can be written as

(27) $Y_t = Z_t K_{t-1}^{\nu} N_t^{1-\nu}/DP_t$,

where $N_t = \int_0^1 N_t(f)df$ is aggregate employment, $K_{t-1} = \int_0^1 K_{t-1}(h)dh$ is the aggregate capital stock, and $DP_t = \int_0^1 (P_t/P_t(f))^{\phi p} df$ is a measure of the price dispersion across firms; DP_t can be written as

(28) $DP_t = (1-\alpha)(P_t/P_t^*(f))^{\phi p} + \alpha(P_t/P_{t-1})^{\phi p} DP_{t-1}$.

The inefficiency due to price dispersion can be seen in equation (27). Each firm has the same marginal cost (equation (3)); so, consumers should choose equal amounts of the firms' products to maximize the consumption good aggregator (4). If prices are flexible ($\alpha = 0$), then $P_t(f) = P_t$ for all f, and this efficiency condition will be met; if prices are sticky ($\alpha > 0$), then product prices will differ, and consumption decisions will be distorted. This distortion is manifested in equation (27). If prices are flexible, $DP_t = 1$ and aggregate output is maximized for a given labor input; if prices are stick, in a second-order approximation $DP_t > 1$, and output will be less for a given labor input.

2.4. Calibration of Model 3 –

Parameters for the calibration of Model 3 are given in Table 1. Several of the parameters were chosen for comparability with EHL. The Calvo parameters, α and ω, were taken from EHL, but as explained in Appendix A, the value for α may be too high. The Frisch elasticity of labor supply, $1/\chi$, is chosen to be roughly consistent with EHL; as explained in Appendix A, it is much higher than estimates found in the literature. RBC models need a very elastic labor supply curve to explain the observed volatility of employment; NNS models with wage inertia do not, since employment is demand determined and workers need not be on their notional labor supply curves. Indeed, Canzoneri, Cumby and Diba (2004) found that the Frisch elasticity is essentially a free parameter in their NNS model; it could be chosen to match estimates in the micro literature. We will explain the significance of this parameter in the next section. The other parameters in Table 1are taken from Canzoneri, Cumby and Diba (2004); see Appendix A.

2.5. Modifications of Model 3 to obtain Models 1, 2, 4 and 5 –

Model 2 does not allow households to accumulate capital. It is the same as Model 3, minus equations (16), (22) and (23); the aggregate capital stock is fixed at its steady state value in Model 3. Model 1 is the same as Model 2, but subsidies are added to eliminate the monopoly distortions; that is, we set $S_w = \mu_w$ and $S_p = \mu_p$. Model 4 assumes capital is both fixed over time, and firm specific. It is like Model 2, but the rental market for capital is eliminated. Model 5 assumes there is no capital. It is like Model 4, but the firm's production function is linear in the labor bundle; that is, (1) reduces to $Y_t(f) = Z_tN_t(f)$. Modifications needed for Model 6 will be discussed in Section IV.

2.6. Welfare –

Our measure of national welfare is

(29) $U_t = E_t\sum_{\tau=t}^{\infty}\beta^{\tau-t}[\log(C_\tau) - (1+\chi)^{-1}AL_\tau]$,

where C_t (= $\int_0^1 C_t(h)dh = C_t(h)$ for all h) is per capita consumption, and $AL_t = \int_0^1 L_t(h)^{1+\chi}dh$ is the average disutility of work. If wages are flexible ($\omega = 0$), then $W_t(h) = W_t$ for all h, and firms hire the same hours of work from each household; $AL_t = \int_0^1 L_t(h)^{1+\chi}dh = L_t(h)^{1+\chi}\int_0^1 dh = L_t(h)^{1+\chi}$. In this special case, households are identical, and our measure of welfare, U_t, reduces to individual household utility.

If wages are sticky ($\omega > 0$), then there is a dispersion of wages that makes firms hire different hours of work from each household. This creates an inefficiency similar to the inefficiency due to price dispersion: the composite labor service used by firms – $N_t = \int_0^1 L_t(h)^{(\phi w-1)/\phi w} dh]^{\phi w/(\phi w-1)}$ – will not be maximized for a given aggregate labor input $\int_0^1 L_t(h)dh$. This distortion in firms' hiring decisions manifests itself in the AL term in equation (29). In Canzoneri, Cumby and Diba (2004), we showed

(30) $AL_t = N_t^{1+\chi} DW_t$

(31) $DW_t = (1-\omega)(W_t^*(h)/W_t)^{-\phi w(1+\chi)} + \omega(W_{t-1}/W_t)^{-\phi w(1+\chi)} DW_{t-1}$.

where $DW_t = \int_0^1 (W_t(h)/W_t)^{-\phi w(1+\chi)} dh$ is a measure of wage dispersion, analogous to DP_t for prices.

2.7. Measuring the welfare costs –

Let V_t be the value function for aggregate welfare in period t, evaluated at the point where state variables are in their non-stochastic steady state.[10] In light of (29), V_t is given by

(32) $V_t = \log(C_t) - (1+\chi)^{-1} AL_t + \beta E_t[V_{t+1}]$.

In the next two sections, we use Dynare to calculate a second order approximation of V_t under various assumptions about nominal inertia and the inflation targeting rule for monetary policy. Let $V_t(\alpha, \omega)$ represent the welfare of an economy with a given type of nominal inertia (characterized by the parameters α and ω) and a given monetary policy rule; then, $V_t(0, 0) - V_t(\alpha, \omega)$ is the difference between welfare in this economy and welfare in an economy that is free of nominal inertia. We will use this as our measure of the efficacy of a given monetary policy rule.

Following Lucas (2003), we can interpret $V_t(0, 0) - V_t(\alpha, \omega)$ as something that has comprehensible units. In particular, this difference in welfare can be interpreted as the percentage of

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[10]The list of state variables depends on the type of nominal inertia present; for notational simplicity, we have suppressed any reference to state variables in the definition of the V function.

consumption households would on average be willing to give up, *holding their work effort constant*, to obtain the flexible wage/price values of consumption and work effort. To see this, let $\{C_j^*\}$ and $\{AL_j^*\}$ be consumption and the average disutility of work in the flexible wage/price solution, let $\{C_j\}$ and $\{AL_j\}$ be consumption and the average disutility of work in the solution with nominal inertia, and let ξ solve:

$$(33)\ V_t(0,0) = E_t\sum_{j=t}^{\infty}\beta^{j-t}[\log(C_j^*) - (1+\chi)^{-1}AL_j^*] = E_t\sum_{j=t}^{\infty}\beta^{j-t}[\log((1+\xi)C_j) - (1+\chi)^{-1}AL_j]$$

$$= \xi/(1-\beta) + E_t\sum_{j=t}^{\infty}\beta^{j-t}[\log(C_j) - (1+\chi)^{-1}AL_j] = \xi/(1-\beta) + V_t(\alpha,\omega)$$

or, assuming $\beta = .99$,

$$(34)\ \xi = (1-\beta)[V_t(0,0) - V_t(\alpha,\beta)] = .01*[V_t(0,0) - V_t(\alpha,\omega)].$$

Our welfare measure,

$$(35)\ V_t(0,0) - V_t(\alpha,\omega) = 100*\xi,$$

has units of percentages of consumption (instead of fractions).

2.8. Summarizing –

Nominal inertia creates two distortions in all of our models: Calvo-style price setting creates a price dispersion that distorts households consumption decisions, and Calvo-style wage setting creates a wage dispersion that distorts firm's hiring decisions. These distortions interact with the distortions created by monopolistic competition to create what we call the 'welfare cost of nominal inertia'. In the next sections, we solve our model numerically to get an idea of the quantitative magnitude of this cost under various assumptions about models and about monetary policy.

III. Price Inflation Targeting and the Modeling of Capital.

In this section, we study price inflation targeting and the modeling of capital. As mentioned in the introduction, some twenty central banks currently practice inflation targeting. One simple way of characterizing inflation targeting is to say that the central bank increases interest rates when inflation rises; the price inflation targeting rule is

(36) $i_t = -\log(\beta) + \theta\pi_t$,

where $\pi_t = \log(P_t/P_{t-1})$. As is well known, the reaction parameter, θ, should be large enough to achieve nominal determinacy. Raising θ above this minimum level decreases inflation volatility and the price dispersion created by Calvo-style price inertia. If price inertia is the only nominal inertia in the model, then it is optimal to let $\theta \rightarrow \infty$, eliminating all inflation volatility and any price dispersion; we call this 'strict price inflation targeting'. EHL showed that strict inflation targeting is no longer optimal when wage inertia is added to the model. In this section, we ask how much a central bank using the inflation targeting rule (36) should clamp down on the volatility of inflation, and how the answer to this question might depend upon the modeling of capital.

Before going on, some discussion of our characterization of inflation targeting, and our terminology, may be appropriate. Our use of the rule (36) to characterize inflation targeting runs the considerable risk of trivializing what is generally viewed as a much more comprehensive framework for implementing monetary policy.[11] Central banks that practice inflation targeting certainly look at more variables than the inflation rate. The output gap is a prominent example; others include monetary aggregates, consumer confidence, interest rate spreads, and exchange rates. The important distinction here is whether these additional variables are independent goals of monetary policy or information variables that help predict future inflation. Our use of (36) to characterize inflation targeting is meant to focus on inflation control as the operational objective of monetary policy; for

[11] See for example Faust and Henderson (2003).

simplicity we abstract from the use of other information.

In the same vein, our terminology is not universal. We think of the rule (36) (with $\theta < \infty$) as 'flexible' inflation targeting; this is in contrast to the definition of 'strict' inflation targeting given above. To some, 'strict' inflation targeting means a rule like (36) that excludes other variables, whatever role – independent goal, information – they might play.

3.1. The cost of nominal inertia and the importance of modeling capital.

Table 2 presents the welfare consequences of price inflation targeting as θ is raised to decrease the volatility of inflation; in all cases, nominal inertia is characterized by $\alpha = \omega = 0.75$. As described above, the welfare measures are expressed in consumption equivalents – the percent of consumption an average household would give up each period to obtain the flexible wage/price values of consumption and work effort. The table starts with an unconditional standard deviation of inflation of 0.0020 per quarter. This is considerably less than the 0.0057 observed in the U.S. data.[12] However, it should be recalled that productivity shocks are the only source of uncertainty in Models 1 through 5; there are no demand side shocks.[13] In successive columns, the volatility of inflation is reduced by a quarter, until – in the last column – we have strict inflation targeting.[14]

Model 1 is quite similar to the EHL model. As the volatility of inflation is reduced, welfare initially approaches the welfare enjoyed in the flexible wage/price solution; this is measured by the

[12]All data generated by the models or reported from actual statistics has been HP filtered. Appendix A gives our data sources.

[13]Our benchmark of 0.0020 came from eliminating the demand side shocks in the model we calibrated in Canzoneri, Cumby and Diba (2004).

[14]The strict inflation targeting figure was calculated by actually setting the $\pi_t = 0$ in Dynare. Experimentation indicates the costs approach the strict inflation targeting figure monotonically as θ becomes sufficiently large.

fall in consumption equivalents. Then, welfare falls (or the consumption equivalents rise) as we proceed to strict inflation targeting. There is clearly an 'optimal' amount of inflation volatility with a rule like (36); strict inflation targeting imposes costs that are about three times larger than is necessary. These costs are not high in absolute terms, but as Canzoneri, Cumby and Diba (2004) have shown, the costs would be considerably higher if we had specified an elasticity of labor supply ($1/\chi$) that is more in line with micro empirical estimates.[15]

Model 1 eliminates the distortions due to monopolistic competition with wage and price subsidies. Model 2 drops these subsidies, and steady state consumption falls by about 12%; however, a comparison of the second and third rows of Table 2 reveals that the reported consumption equivalents are hardly affected. Monopolistic competition creates large distortions in NNS models, but apparently these distortions do not interact with the distortions created by nominal inertia in a significant way. This is an interesting result in its own right. Using the linear-quadratic methods introduced by Rotemberg and Woodford (1997), the modeler was compelled to use subsidies to eliminate the distortions due to monopolistic competition; using the methods employed here, it is a modeling choice. There are good arguments for, and against, using these subsidies; our results suggest that the question is moot as far as the welfare implications of nominal inertia in NNS models are concerned.

Model 3 allows households to accumulate new capital over time, and Model 4 makes capital firm specific (without allowing investment). These are potentially important differences in the way capital is modeled, but the results reported in Table 2 are rather similar to the results for Model 2.

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[15]If for example the elasticity is lowered to 0.143 ($\chi = 7$), then the cost of strict price inflation targeting in Model 2 rises from the 0.255 reported in Table 2 to 1.184 percent of consumption.

The consumption equivalents are small in absolute terms regardless of the policy rule. As the volatility of inflation is reduced the consumption equivalents fall and then rise. The costs of strict inflation targeting are about three times larger than necessary. Apparently, the modeling choices involving capital are not very significant for the questions at hand.

If the way in which capital is modeled does not matter, perhaps it is not necessary to model capital at all. Model 5 tests this proposition. Model 5 has no capital; production is linear in the labor bundle. The last row in Table 2 shows that the model without capital behaves quite differently. Welfare falls dramatically as inflation volatility is reduced: when three quarters of the volatility is eliminated, the cost is 3 percent of consumption; when all volatility is eliminated, the cost rises to a staggering 20 percent of consumption. Strict inflation target is a disaster in this NNS model without capital, but results for the four previous models show that this result is misleading.

The bottom line seems to be that it is very important to model capital when assessing the efficacy of inflation targeting rules like (36), but that the particular way in which capital is modeled may not be too important. It is not immediately apparent why including capital in the model should be so important. This is a subject to which we turn next.

3.2. How capital lowers the cost of stringent inflation targeting.

The role played by capital is easiest to understand if we assume that prices are flexible ($\alpha = 0$). We begin with that case, and we compare Model 2 (mobile capital, no accumulation) with Model 5 (no capital). Figures 1 and 2 show how consumption (C_t), employment (N_t) and the relative new wage (W^*_t/W_t) in the two models respond to a positive productivity shock, Z_t; the relative new wage may be viewed as a measure of wage dispersion. The first row in each figure shows how these variables respond when wages are also flexible ($\omega = 0$). In both models, output and consumption rise in proportion with Z_t, while employment and the relative new wage are unaffected.[16, 17] The second row in each figure shows how these variables respond when wages are sticky ($\omega = 0.75$).

In both models, consumption rises more when wages are sticky than when wages are flexible; employment and the relative new wage also rise when wages are sticky. All three of these facts lower utility (compared to utility with flexible wages), and all of these facts are much more pro-nounced in the model without capital. Why is this so?

When (as we are assuming) prices are flexible, firms set prices as a markup over marginal cost; in light of equations (2) and (3),

(37) $P_t = \mu_p MC_t \propto (N_t/K_t)^{\nu} W_t/Z_t \propto R_t^{\nu} W_t^{1-\nu}/Z_t$.

In Model 2 (with capital), $0 < \nu < 1$; in Model 5 (with no capital), production is linear in N_t, and $\nu = 0$. When Z_t increases, firms facing given wage and rental rates want to lower prices. But, if inflation targeting is stringent, the central bank limits the fall in prices, and something else has to bring equation (37) back into balance; something has to raise marginal cost enough to fill the gap. The central bank keeps prices from falling by lowering the interest rate; this stimulates demand for output and employment. In a model without capital ($\nu = 0$), the increase in employment makes new wages rise enough for the aggregate wage (W_t) to fill the gap, and (as discussed in the last section) this creates wage dispersion that lowers welfare. In a model with capital ($\nu > 0$), there is more flexibility. A rise in employment relative to the capital stock (or equivalently, an increase in the rental rate, if capital is mobile across firms) increases marginal cost; employment and new wages

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[16]Dynare shows a blank graph when there is no response.

[17]Employment is unaffected because of the logarithmic utility of consumption. The relative new wage is unaffected because wages are flexible and all wages move in tandem.

do not have to rise as much as in the model without capital. This happens in all of the models with capital.

Adding price inertia complicates the story. Now only some firms are allowed to lower their prices in response to an increase in productivity, and the resulting price dispersion affects welfare. However, the same basic reasoning seems to hold. Figure 3 reports the same impulse response functions for Model 2 (mobile capital, no accumulation), but with both price and wage inertia. In the first row of Figure 3, we again have flexible prices and wages ($\alpha = \omega = 0$) ; in the second row, we have price and wage inertia ($\alpha = \omega = 0.75$) and flexible inflation targeting (θ large enough that the standard deviation of $\pi = 0.0010$); and in the third row, we have price and wage inertia and strict inflation targeting. The first row looks exactly like the first row of Figure 1; in the second row, consumption rises further than in the first row, and both employment and the relative new wage rise; and in the third row, these three effects are magnified.

IV. Wage and Price Inflation Targeting

EHL have shown that price inflation targeting – as characterized by the rule (36) – is not an optimal monetary policy strategy in an NNS model that includes wage inertia. In that case, EHL showed that the central bank should also respond to either the output gap or wage inflation. In fact, when wage inertia is the only nominal inertia, strict wage inflation targeting achieves the optimal solution. It is natural to think of monetary policy controlling something nominal; and wage inflation targeting is a natural alternative to price inflation targeting. So, in this section we will compare wage inflation targeting to price inflation targeting.

Wage inflation targeting is characterized by the rule

(38) $i_t = -\log(\beta) + \theta w\pi_t$,

where $w\pi_t = \log(W_t/W_{t-1})$; clearly, (38) is analogous to the price inflation targeting rule (36). First, we study wage inflation targeting in the models that were analyzed in the preceding section. Then, we analyze the robustness of our results by extending Model 3 to include habit formation and various demand side shocks. And finally, we compare our price and wage inflation targeting rules to hybrid rules that respond to movements in both prices and wages.

4. 1. Wage and price inflation targeting in Models 2, 3, 4, and 5.

Table 3 is analogous to Table 2; it presents the welfare implications in the four models of raising θ in (38) to decrease as the volatility of wage inflation. The welfare measures are again consumption equivalents – the percent of consumption an average household would give up each period to obtain the flexible wage/price values for consumption and work effort.

Table 3 tells a very different story than Table 2. With wage inflation targeting, welfare rises monotonically as the volatility of wage inflation is reduced. When using a wage inflation targeting rule like (38), the central bank should make the volatility as small as possible.

Perhaps the most striking result in Table 3 is that the numbers are generally much smaller than those in Table 2, especially as the targeting rule gets tighter; comparing 'strict' targeting rules, the consumption equivalents are an order of magnitude smaller in Table 3. This holds for all of the ways of modeling capital (Models 2, 3 and 4), and for the model with no capital (Model 5). In fact, the consumption equivalent with strict wage targeting is three orders of magnitude smaller in the model without capital. If the choice is between the simple price and wage targeting rules (36) and (38), the wage targeting rule is the clear winner.

The superiority of the wage targeting rule holds for all of the models we have considered;

in this sense, the result appears to be robust. It is possible, however, that the wage targeting rule's superiority is due to some feature that all of the models have in common. So, we used Model 2 (the EHL model, minus the subsidies) to perform a few robustness checks; the results are reported in Table 4. Here, we compare price and wage inflation targeting rules with the parameter θ set at six: with price inflation targeting, $\theta = 6$ makes the standard deviation of price inflation about 0.0010; and with wage inflation targeting, $\theta = 6$ makes the standard deviation of wage inflation about 0.0001.

All of the models we discuss above assume logarithmic utility of consumption. The first robustness check is to convert to a constant elasticity specification.[18] The second column of Table 4 gives the consumption equivalents when the coefficient of relative risk aversion is 4. Once again, strict wage inflation targeting dominates price inflation targeting and gets quite close to the level of welfare with flexible wages and prices. Our results do not appear to be due to the logarithmic utility of consumption.

All of the models discussed above have nominal inertia characterized by $\alpha = \omega = 0.75$, as in the EHL model; the average duration of wage and price contracts is four quarters. Price inflation targeting reduces price dispersion, and works well against price inertia; wage inflation targeting reduces wage dispersion, and works well against wage inertia. The next set of robustness checks varies the degree of nominal inertia in prices and wages. The third column of Table 4 reproduces the benchmark case. The fourth column reduces price inertia; with $\alpha = 0.50$, the average duration of a price contract is just two quarters. The consumption equivalent falls under wage inflation

[18]That is, $\log(C_\tau(h))$ in equation (14) is replaced by $(1-\gamma)C_\tau(h)^{1-\gamma}$.

targeting, but somewhat paradoxically, it rises under price inflation targeting.[19] Here again, wage inflation targeting is clearly better. The fifth and sixth columns take price inertia back to its original level, but decrease wage inertia. When the average duration of wage contracts is reduced to two quarters, wage inflation targeting still does better than price inflation targeting. When wages are completely flexible, price inflation targeting does better in relative terms, but wage inflation targeting does not do badly in absolute terms.

In summary, the wage inflation targeting rule (38) dominates the price inflation targeting rule (36) in all of the models we have considered so far. However, Models 1 through 5 are very stylized. For one thing, productivity shocks are the only source of uncertainty. This is in keeping with the EHL analysis, and many (if not most) of the NNS models used to evaluate monetary policy in the literature. However, more elaborate modeling efforts have added demand side shocks, and other features to make the models fit the data better.[20] It would be interesting to see if wage inflation targeting's superiority holds in a more complex environment. We turn to this next.

4. 2. Wage and price inflation targeting in Model 6.

Model 6 extends Model 3 (which was outlined in Section II) in three ways: it adds government spending; it adds a discount rate shock; and it adds habit formation to consumption decisions. First, we describe the required modifications to Model 3, and how we calibrate the resulting Model 6 to fit certain aspects of the U.S. data; then, we evaluate the inflation targeting rules, (36) and (38),

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[19]As is well known, when there are multiple distortions, reducing one distortion need not improve welfare. Lowering wage inertia increases the cost of nominal inertia even when we use subsidies to eliminate the distortions to monopolistic competition.

[20]Examples include Christiano, Eichenbaum and Evans (2001), Smets and Wouters (2002), Ireland (2002), Collard and Dellas (2003), the IMF's GEM, and the FRB's SIGMA.

in this more elaborate framework.

4. 2. 1. Model 6 and its calibration.

To incorporate habit and a discount rate shock, we extend the utility function (14) to:

(39) $U_t(h) = E_t\sum_{\tau=t}^{\infty}\beta^{\tau-t}a_t[\log(C_\tau(h) - bC_{\tau-1}(h)) - (1+\chi)^{-1}L_\tau(h)^{1+\chi}]$.

a_t is the discount rate shock, and the parameter b measures the strength of habit in consumption decisions; when a_t is set to 1 and b is set to zero, (39) reverts to (14). These modifications in the utility function require changes in the household's first order conditions, but they are straightforward.

Following Ireland (2002), we model the logarithm of the discount rate shock as an autoregressive process:

(40) $\log(a_t) = 0.96\log(a_{t-1}) + \epsilon_{a,t}$,

where the standard deviation of the innovation is 0.0188; the estimation of this equation is Ireland's. We also model the logarithm of government spending as an autoregressive process:

(41) $\log(G_t) = \zeta + 0.973\log(G_{t-1}) + \epsilon_{g,t}$,

where the standard error of the innovation is about 0.01; the intercept term, ζ, is chosen to make G/Y = 0.20 in the steady state. Data sources and the estimation are described in Appendix A.

For calibration purposes, we estimated a standard rule to describe monetary policy:

(42) $i_t = 0.222 + 0.824i_{t-1} + 0.35552\pi_t + 0.032384(y_t - y_t^*) + \epsilon_{i,t}$,

where y_t^* is potential output, $y_t - y_t^*$ is the output gap, and the standard deviation of the interest rate shock, $\epsilon_{i,t}$, is .00245. Data sources and the estimation are described in Appendix A. However, one issue requires some discussion here: potential output (however defined) is not a variable that is observed directly. This causes problems in estimation and in application. In EHL and in our Model

6, y^*_t is assumed to be the flexible wage/price output.[21] The central bank observes y^*_t with error, and measurement errors are absorbed in the residual term; so, in calibrating Model 6, we let the standard deviation of the interest rate shock be 0.0049, twice its estimated value. This assumption helps in the calibration exercise that follows. It should be emphasized that we only use policy rule (42) in calibrating the model; in evaluating price and wage inflation targeting we use the rules (36) and (38).

Table 1a specifies the rest of Model 6's parameters; most are the same as in Table 1. There are a few exceptions. We have lowered price inertia so that the average duration of price contracts is two quarters; our justification for this is given in Appendix A. This modification helps Model 6 explain the observed volatility in U.S. inflation.[22] We have increased ψ to limit the fluctuations in investment. And the value for the new parameter b is typical in the literature.

Table 5 compares results from our calibrated Model 6 with some standard features of the U.S. economy. The model's variables are expressed as log deviations form a non-stochastic steady state. The U.S. data are also in logs, and both the model data and the actual data have been HP-filtered. Dynare was used to calculate the model's steady state, find a first order approximation, and calculate the moments reported in Table 5. Beginning with the column for y, 0.015 is the model's standard deviation of output; it is slightly smaller than the standard deviation of output in the data, 0.016. Proceeding to the column for inv, 3.9 is the ratio of the model's standard deviation of investment to the model's standard deviation of output; it is somewhat higher than the corresponding

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[21] We follow Neiss and Nelson (2003) in computing potential output from the flexible wage/price values for both capital and labor.

[22] Getting enough inflation volatility can be a problem in NNS models. One approach, used by Smets and Wouters (2002), is to model price markup shocks; another would be to model a flexible price sector. These two approaches have very different normative implications.

ratio in the data, 3.1. The second number in the cell, 0.89, is the model's correlation between investment and output; it is the same as the correlation in the data. The columns for c, n, w and inf provide the corresponding moments for consumption, employment, the real wage and inflation.

The first thing to note in Table 5 is that – with a few exceptions – Model 6 comes close to matching the moments in the data. There are some exceptions. Inflation and output are (slightly) negatively correlated in the model, while they are positively correlated in the data; and real wages and output are more positively correlated in the model than they are in the data. These facts suggest that the model may be missing some demand side shocks, or that the shocks that have been included may not have been modeled correctly.[23] Figure 4 shows impulse response function for the four shocks in Model 6.[24] The model does not capture the persistence that is observed in U.S. time series. But, on the whole, the calibrated Model 6 bears some resemblance to the U.S. economy.

4. 2. 1. The attractiveness of wage inflation targeting in Model 6.

In the benchmark run of Model 6, the standard deviation of price inflation is 0.0048 and the standard deviation of wage inflation is 0.0014. Tables 7a and 7b are analogous to Tables 1 and 2; they present the consumption equivalents as θ is raised in (36) and (38) to reduce the volatility of

[23] This discrepancy would have been more pronounced if we had not doubled the standard deviation of ϵ_i in (42). Changing the standard deviation of ϵ_i had little impact on the other moments we report.

[24] Of particular interest to us are the pictures for government spending. An increase in government spending crowds out consumption. This fact appears to be at odds with the empirical work of Blanchard and Perotti (2001) and Fatas and Mihov (2000a, b). Table 6 reports an infinite horizon variance decomposition for Model 6. The beta shock and the government spending shock do rather little in the model. These facts may be additional indications that the demand side of Model 6 (and NNS models generally) needs further work.

price and wage inflation from their benchmark values to zero.[25] The tables also report the standard deviation of the variable not being targeted and standard deviation of the nominal interest rate.[26]

We begin with price inflation targeting and Table 7a. As the volatility of price inflation is reduced, consumption equivalents fall and then rise as we proceed to strict inflation targeting. As in the earlier models, there is clearly an 'optimal' amount of inflation volatility with a rule like (36); strict inflation targeting imposes costs that are about four times larger than is necessary. Moving to wage inflation targeting and Table 7b, another familiar pattern emerges. As the volatility of wage inflation is reduced, consumption equivalents fall monotonically. With a wage inflation targeting rule like (38), the less wage volatility the better.

Comparing Tables 7a and 7b, it appears that price inflation targeting is better when the targeting rules are loose, and wage inflation targeting is better when the rules are strict. This is however somewhat misleading. When wage inflation targeting is used to bring the standard deviation of wage inflation to its benchmark of 0.0014, the standard deviation of price inflation is 0.0054, higher than its benchmark of 0.0048. Wage inflation targeting has to be very tight to bring the volatility of price inflation down to its benchmark level. In other words, if wage inflation targeting were used instead of price inflation targeting to produce the benchmark level of price inflation volatility, the consumption equivalent would be an order of magnitude smaller.

4. 2. 2. Wage inflation targeting versus a hybrid rule.

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[25]We calculated the strict price and wage inflation targeting figures by actually setting the price and wage inflation equal to zero in Dynare. Experimentation indicates that the consumption equivalents approach their strict inflation targeting values monotonically as θ is increased.

[26]For comparison, we note that, for quarterly HP-filtered data, the standard deviation of U.S. CPI inflation is 0.00576 and the standard deviation of the federal funds rate is 0.0040.

EHL showed that a hybrid rule which reacts to price and wage movements is preferable to either of our targeting rules – (36) or (38) – when both price and wage inertia are present. We have shown that a tight form of wage inflation targeting works very well in Model 6. But, consider the hybrid rule

(43) $i_t = - \log(\beta) + \theta_p \pi_t + \theta_w w\pi_t$,

where $\pi_t = \log(P_t/P_{t-1})$ and $w\pi_t = (W_t/W_{t-1})$. Can this hybrid rule actually do much better than pure wage inflation targeting in Model 6?

Table 8 compares pure wage inflation targeting with the hybrid rule. The second row shows how the standard deviation of wage inflation falls as θ_w is tightened in the pure wage inflation targeting rule (where $\theta_p = 0$). The third row presents the consumption equivalents with the pure wage inflation targeting rule. The forth row shows the optimal θ_p for the value of θ_w given in the first row. And finally, the fifth row presents the consumption equivalents for the hybrid rule.

When the pure wage inflation targeting rule is loose ($\theta_w = 2$), it does not do very well; it is not much better than price inflation targeting. A hybrid rule that puts roughly equal weight on price and wage movements does three times better. As the pure wage inflation targeting rule is tightened (by raising θ_w), it does much better; the consumption equivalent falls to its strict targeting value monotonically. And as θ_w is increased, the optimal value of θ_p in the hybrid rule becomes smaller – in actual values initially, and then in relative terms – and the consumption equivalent associated with the hybrid rule also falls. The hybrid rule does better than pure wage inflation targeting for all values of θ_w, but as the value of θ_w is increased, the difference becomes very small. In other words, tight wage inflation targeting appears to be almost as good as the optimal hybrid rule.

V. Conclusion

Our main results can be summarized as follows: It is very important to model capital when examining the welfare effects of inflation targeting rules. However, it does not seem to matter much how capital is modeled; in particular, making capital firm specific did not seem to have the big normative effects that some might have expected. When there is some wage rigidity and monetary policy responds only to price inflation, there is an 'optimal' volatility of price inflation; reducing inflation volatility beyond a certain point will actually lower welfare. The King and Wolman policy of fixing the price level leads to a welfare loss three or four times larger than necessary. By contrast, when there is price rigidity and monetary policy responds only to wage inflation, the tighter the targeting rule the better. In this sense, the best wage inflation targeting rule is easier to describe, and it is more robust across models. And finally, a tight form of wage inflation targeting appears to strongly dominate price inflation targeting, and it appears to be almost as good as the best hybrid rule reacting to both wages and prices.

The bottom line for policy is somewhat provocative. Wage inflation targeting seems very attractive. It is easy to explain, and presumably to implement, and its good performance vis a vis price inflation targeting and hybrid rules seems to be robust across a variety of models.

What is the bottom line for NNS modeling?[27] The bottom line would seem to be implicit in

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[27]From a narrower point of view, there are a number of modeling issues that arise from our work. Calvo 'contracts' may overstate the welfare consequences of nominal inertia; Taylor 'contracts' are an alternative framework worth pursuing. Perhaps more important, our Model 6 suggests (to us anyway) that the modeling of 'demand' shocks should be investigated further. For example, fiscal spending shocks crowd out consumption as well as investment (see Figure 4), and fiscal spending shock and the discount factor shock combined only explain 1.5% of the variation in inflation (see Table 6). Furthermore, Model 6 has difficulty explaining the amount of inflation volatility observed in the U.S. data (recall: we had to augment the volatility of the interest rate shock), and inflation and output are negatively correlated in Model 6.

a question we have not yet answered: why does wage inflation targeting do so well in NNS models with both price and wage inertia? Or equivalently, why does wage inertia appear to be more costly than price inertia. We can only speculate as to the answers. Price inertia creates price dispersion across firms, which leads to inefficiencies in consumption decisions. The welfare cost of these inefficiencies is apparently small in the models we consider. Wage inertia creates wage dispersion across households, which leads to inefficiencies in hiring decisions. Our assumption of complete consumption risk sharing minimizes the cost of consumption volatility. By contrast, individual workers bear the risk of fluctuations in their employment, and this magnifies the cost of aggregate employment volatility.

This ultimately leads us back to a fundamental question raised by Goodfriend and King (2001), who question the relevance of observed wage inertia on theoretical grounds: "... there is a fundamental asymmetry between product and labor markets. The labor market is characterized by long term relationships where there is opportunity for firms and workers to neutralize the allocative effects of temporarily sticky nominal wages. ... (However), spot transactions predominate in product markets where there is much less opportunity for the effects of sticky nominal prices to be privately neutralized." If in fact wages are not allocative, then the part of our models that make wage inflation targeting attractive have been misspecified. On the other hand, a growing empirical literature suggests that wage inertia helps NNS models explain the U.S. data: for example, Christiano, Eichenbaum and Evans (2001) found that wage stickiness helps explain persistence in the effects of monetary shocks, and Smets and Wouters (2002, 2003) showed that wage stickiness also helps explain other features of the data. If in fact wages are not allocative, then NNS modelers will need to find alternative ways of patching these holes.

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Table 1: Parameters for Calibration of Model 3.

$1/\chi$	ρ	σ	α	ω	ϕ_p	ϕ_w	δ	ψ	ν	β
1	0.930	0.008	0.75	0.75	7	7	0.025	8	0.25	0.99

Source: see Appendix A.

Table 1a: Parameters for Calibration of Model 6.

$1/\chi$	ρ	σ	α	ω	ϕ_p	ϕ_w	δ	ψ	ν	β	b
1	0.930	0.008	0.50	0.75	7	7	0.025	16	0.25	0.99	0.7

Sources: see Appendix A.

Table 2: Inflation Targeting and the Modeling of Capital.

STD of π	0.0020	0.0015	0.0010	0.0005	0.0000
Model 1	0.096	0.083	0.107	0.158	0.257
Model 2	0.097	0.084	0.107	0.157	0.255
Model 3	0.150	0.122	0.143	0.220	0.336
Model 4	0.341	0.152	0.067	0.098	0.255
Model 5	0.112	0.268	0.801	2.803	20.912

Table 3: Wage Inflation Targeting and the Modeling Capital.

STD of $w\pi$	0.0003	0.0002	0.0001	0.0000
Model 2	0.049	0.043	0.036	0.028
Model 3	0.058	0.055	0.045	0.036
Model 4	0.062	0.051	0.043	0.034
Model 5	0.041	0.038	0.032	0.026

Table 4: Robustness of Strict Wage Targeting Result in Model 2.

$\theta = 6$	$\gamma = 4$	$\alpha = 0.75$ $\omega = 0.75$	$\alpha = 0.50$ $\omega = 0.75$	$\alpha = 0.75$ $\omega = 0.50$	$\alpha = 0.75$ $\omega = 0.00$
pπ targeting	0.0922	0.1068	0.1361	0.0518	0.0004
wπ targeting	0.0364	0.0361	0.0188	0.0332	0.0323

Table 5: Calibration of Model 6.

std / cor	c	inv	y	n	w	inf
Model 6	0.81 0.85	3.9 0.89	0.015 1.000	0.92 0.64	0.61 0.61	0.33 -0.06
U.S. data	0.80 0.87	3.1 0.89	0.016 1.000	0.90 0.86	0.47 0.24	0.36 0.33

Notes:
1. Both model data and actual data are in logarithms, and have been HP-filtered.
2. Model data was generated by Dynare, using 1st order approximations.
3. Actual data are computed using a sample of 1960:1 to 2003:2.
4. Standard deviations for the y column are the first number in each cell. For other columns standard deviations relative to standard deviation of output are the first numbers in each cell. As both n and w are for the nonfarm business sector, we normalize their standard deviations by the standard deviation of real GDP of the nonfarm business sector.
5. Correlations with output are the second number in each cell.

Table 6: Variance Decomposition (in percent) for Model 6.

	ϵ_p	ϵ_i	ϵ_a	ϵ_g
c	61.59	27.39	9.56	1.46
inv	40.22	51.20	8.54	0.04
y	55.88	42.48	0.23	1.41
n	7.74	88.79	0.48	2.99
w	96.46	3.06	0.28	0.21
y^*	93.62	0.00	3.52	2.86
gap	5.74	92.27	1.95	0.04
π	82.58	16.09	1.06	0.27
i	22.76	75.75	1.41	0.09

Table 7a: Price Inflation Targeting in Model 6.

STD of π	0.0048	0.0036	0.0024	0.0012	0.0000
Cons Equiv	0.334	0.154	0.189	0.371	0.673
STD of wπ	0.0010	0.0007	0.0013	0.0020	0.0028
STD of int	0.0101	0.0135	0.0164	0.0189	0.0209

Table 7b: Wage Inflation Targeting in Model 6.

STD of wπ	0.0014	0.0011	0.0007	0.0004	0.0000
Cons Equiv	0.640	0.422	0.180	0.090	0.029
STD of pπ	0.0054	0.0053	0.0052	0.0051	0.0048
STD of int	0.0021	0.0019	0.0015	0.0013	0.0024

Table 8: Wage Inflation Targeting vs Hybrid Rules in Model 6.

θ_w	2	4	16	256	∞
STD wπ	0.0008	0.0003	0.0001	0.0000	0.0000
w targeting	0.2061	0.0588	0.0333	0.0289	0.0286
optimal θ_p	2.25	1.50	1.75	10	
hybrid rule	0.0664	0.0399	0.0266	0.0255	

Figure 1: Model 2 (Capital Mobility, no Accumulation, Flexible Prices); Productivity Shock.

Figure 2: Model 5 (No Capital, Flexible Prices); Productivity Shock.

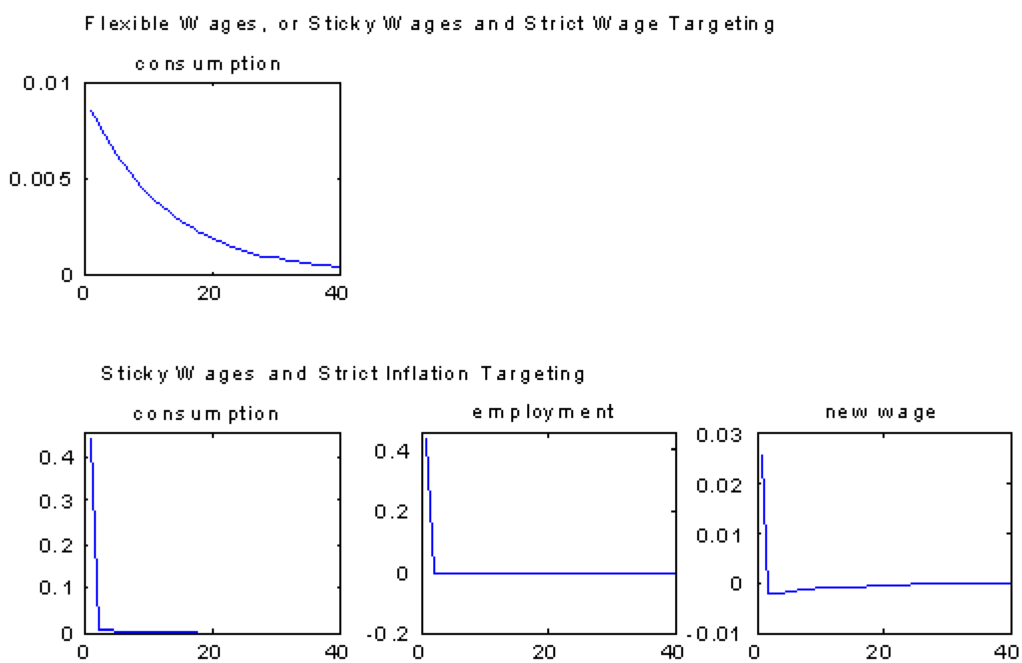


Figure 3: Model 2 (Capital Mobility, no Accumulation); Productivity Shock.

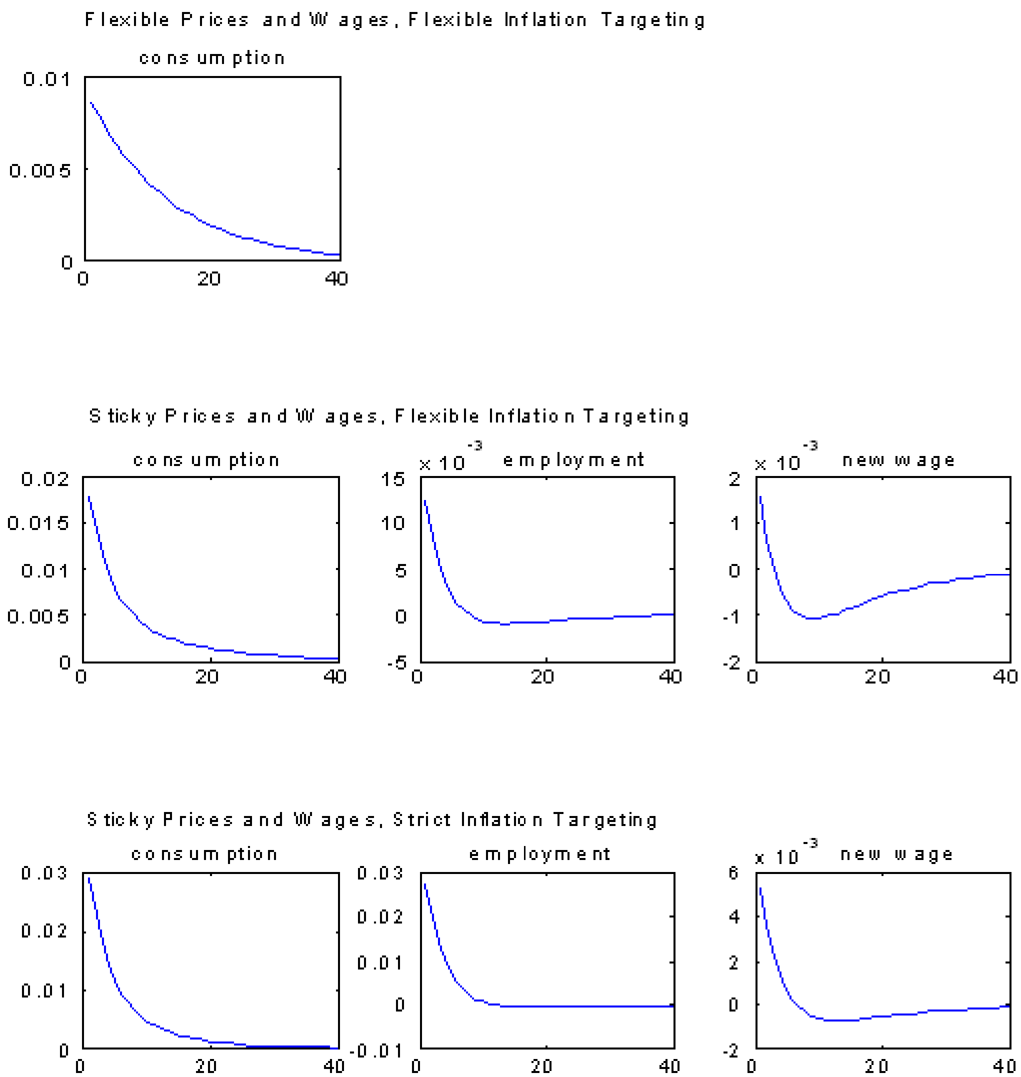
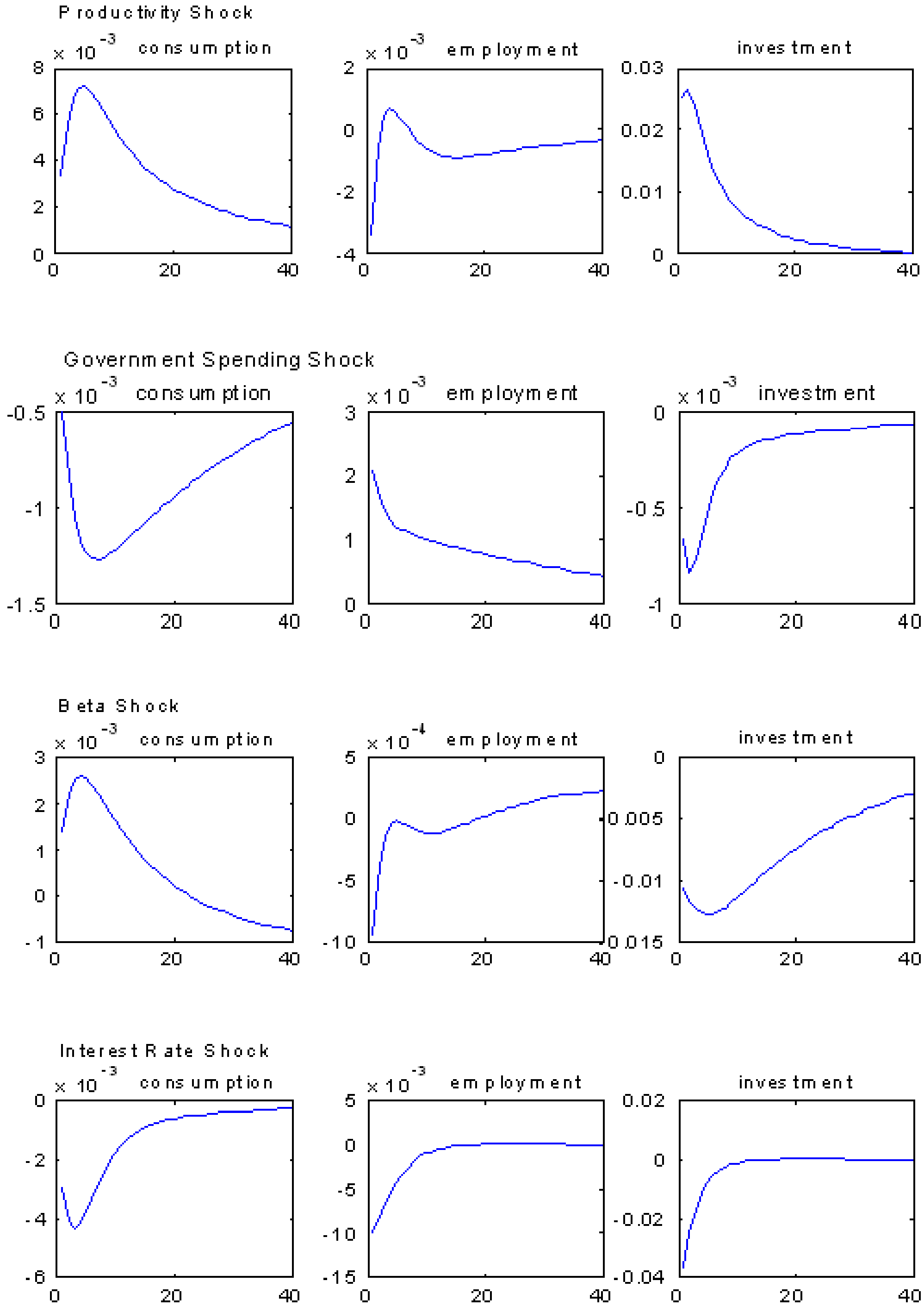


Figure 4: Model 6 with Sticky Prices and Wages, Interest Rate Rule



Appendix A: Choosing Parameters for the Model Calibrations.

I. Estimated Parameters.

Interest rate rule: A substantial literature suggests that monetary policy during the Volker and Greenspan eras can be well described by an interest rate rule of the form,

$$i_t = \gamma_0 + \gamma_1 i_{t-1} + (1-\gamma_1)\gamma_2 \pi_t + (1-\gamma_1)\gamma_3 (y_t - y_t^*) + \epsilon_{i,t},$$

We use nonlinear least squares to estimate the interest rate rule from 1979:3 - 2003:2 and obtain,

γ_0	γ_1	γ_2	γ_3	$\sigma_{\epsilon i}$
0.222 (0.288)	0.824 (0.046)	2.020 (0.342)	0.184 (0.090)	2.44×10^{-3}

Standard errors are in parentheses. Details on all data series are found below.

Productivity: We take the deviation of the log of total factor productivity, z_t, from an estimated linear trend and estimate the autoregression, $z_t = \rho z_{t-1} + \epsilon_{p,t}$ over the period 1960:1 - 2003:2.

ρ	$\sigma_{\epsilon p}$
0.923 (0.027)	8.61×10^{-3}

Government Purchases: As with productivity, we take the deviation of the log of government purchases from an estimated linear trend and estimate the autoregression, $g_t = \zeta + \rho_g g_{t-1} + \epsilon_{g,t}$.

ρ_g	$\sigma_{\epsilon g}$
0.973 (0.015)	1.00×10^{-2}

We then set the constant term in this process so that the model produces a value of G/Y = 0.20 in the steady state.

II. Other Parameters

α: Firms reset prices each quarter with probability $1-\alpha$, so that the mean time between price changes is $(1-\alpha)^{-1}$. Taylor (1999) surveys a large literature and concludes, "price changes and wage changes have about the same average frequency – about one year." This would suggest that we set $\alpha = 0.75$. His conclusion is consistent with the results reported in Gali and Gertler (1999) and Spordone (2001). More recently, Begnino and Woodford (2003) state that survey evidence suggests prices are set slightly less frequently than twice a year, which would suggest using a value for α close to 0.5. Bils and Klenow (2002) report evidence that consumer prices are adjusted on average considerably more frequently than once a year. In Section III, we follow EHL in setting $\alpha = 0.75$. In Section IV, we set $\alpha = 0.5$ in model VI.

ω: Workers reset wages each quarter with probability $1-\omega$, so that the mean time between wage changes is $(1-\omega)^{-1}$. We follow the evidence surveyed in Taylor (1999) and set $\omega = 0.75$ so that wages are reset annually on average.

ϕ_p: We set the elasticity of substitution across goods, $\phi_p = 7$, so that the markup of price over marginal cost, $\mu_p = \phi_p/(\phi_p-1)$ is about 17 percent. Estimates of the markup reported in the literature vary across sectors from about 11 percent to 23 percent. See Bayoumi, Laxton, and Pesenti (2003). Although the evidence suggests that the15 percent markup used by Rotemberg and Woodford (1997) is a reasonable value for the U.S. manufacturing sector, the evidence cited in Bayoumi, Laxton, and Pesenti indicates that markups outside of manufacturing are higher. As a result we selected a value in the middle of the range of values in Bayoumi, Laxton, and Pesenti.

ϕ_w: We set the elasticity of substitution across workers, $\phi_w = 7$, so that the wage markup, $\mu_w = \phi_w/(\phi_w-1)$ is about 17 percent. This is based on evidence on inter-industry wage differentials discussed in Bayoumi, Laxton, and Pesenti (2003).

ν: We set the capital share to be 0.25. Prices are set so that $P = \mu_p MC$, and marginal cost can be written as the ratio of wages to the marginal product of labor. Thus $P = \mu_p [WN/(1-\nu)Y]$ and $(1-\nu) = \mu_p[WN/PY]$. The labor share of compensation (compensation of employees plus two-thirds of proprietors' income relative to GDP - indirect business taxes) in U.S. data averaged about two-thirds between 1960:1 - 2003:2. With a markup of about 17 percent, this suggests a value of ν = 0.25.

δ: We set $\delta = 0.025$ so that 2.5 percent of the capital stock depreciates each quarter. This value is widely used in the literature. When combined with our value of ν and our steady state calibration of $G/Y = 0.20$, this assumption yields steady state values of $I/Y = 0.15$ and $C/Y = 0.65$.

ψ: We set the capital adjustment cost parameter, ψ, in order to match the relative volatilities of investment and output as closely to the data as possible. In Model III, we take the value $\psi = 8$ from Canzoneri, Cumby and Diba (2003); in Model VI, we set $\psi = 16$.

β: We set the discount factor, $\beta = 0.99$.

III. The Data

G: Real government consumption and gross investment per capita. Real government consumption and gross investment is from NIPA Table 1.2 and population is from NIPA Table 8.7.

I: Real fixed investment per capita. Real fixed investment is computed as the ratio of fixed investment to the implicit price deflator for fixed investment. Fixed investment is from NIPA Table

1.1, the implicit deflator for fixed investment is from NIPA Table 7.1, and population is from NIPA Table 8.7

i: Effective Federal Funds rate from the historical data from Federal Reserve Release H.15. They are reported in percent per annum. Before running the regressions for the interest rate rule, we divided by 1200 to convert to a decimal amount per month.

K: Real nonresidential fixed assets. We follow Stock and Watson (1999) in constructing our measure of the capital stock. We begin by computing real nonresidential fixed assets by taking the ratio of nonresidential fixed assets to the implicit deflator for fixed investment. This yields an annual series for fixed capital. We create a quarterly series by interpolating using the quarterly values for real fixed investment.

N: Hours worked per capita. We take hours worked from the BLS index of aggregate hours worked in the nonfarm business sector from historical data from Table 2 of the BLS Productivity and Cost releases. Population is from NIPA Table 8.7.

π: Inflation, computed as $\log(P_t/P_{t-1})$, where P_t is the CPI-U.

W: Real hourly compensation. We take real hourly compensation for the nonfarm business sector from historical data from Table 2 of the BLS Productivity and Cost releases.

y: Real per capita GDP, taken from NIPA Table 8.7.

y*: Per capita potential GDP. We use the Congressional Budget Office's estimate of potential GDP. The data are from Backup Data for Table 2-5, Key Assumptions in CBO's Projection of Potential GDP (By calendar year) The Budget and Economic Outlook: Fiscal Years 2004-2013, January 2003 and are posted on the CBO web site. Population is from NIPA Table 8.7.

z: Total factor productivity, computed as $z_t = ynfb_t - \nu \log(K_t) - (1-\nu) \log(N_t)$. The log of real GDP in the nonfarm business sector (ynfb) is from NIPA table 1.8. In computing total factor productivity, we use aggregate hours worked, rather than aggregate hours worked per capita.