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Optimal monetary policy with the cost channel☆

Federico Ravenna[a], Carl E. Walsh[a,b,*]

[a]*Department of Economics, University of California, Santa Cruz, CA 95064, USA*
[b]*Federal Reserve Bank of San Francisco, 101 Market St., San Francisco, CA 94105, USA*

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Abstract

In the standard new Keynesian framework, an optimizing policy maker does not face a trade-off between stabilizing the inflation rate and stabilizing the gap between actual output and output under flexible prices. An ad hoc, exogenous cost-push shock is typically added to the inflation equation to generate a meaningful policy problem. In this paper, we show that a cost-push shock arises endogenously when a cost channel for monetary policy is introduced into the new Keynesian model. A cost channel is present when firms' marginal cost depends directly on the nominal rate of interest. Besides providing empirical evidence for a cost channel, we explore its implications for optimal monetary policy. We show that its presence alters the optimal policy problem in important ways. For example, both the output gap and inflation are allowed to fluctuate in response to productivity and demand shocks under optimal monetary policy.

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*Corresponding author. Department of Economics, Division of Social Sciences I, University of California, 1156 High Street, Santa Cruz, CA 95064-1099, USA. Tel.: +1 831 459 4082.
E-mail address: walshc@ucsc.edu (C.E. Walsh).

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1. Introduction

In the standard new Keynesian framework, an optimizing policy maker does not face a trade-off between stabilizing the inflation rate and stabilizing the gap between actual output and output under flexible prices. The result that the optimal policy problem has a trivial solution is widely recognized as a shortcoming of this framework. Clarida et al. (1999) show that the introduction of an ad hoc, exogenous cost-push shock allows the new Keynesian model to generate a meaningful policy problem. In this paper, we show that a cost-push shock arises endogenously in the presence of a cost channel for monetary policy. A cost channel is present when firms' marginal cost depends directly on the nominal rate of interest. Barth and Ramey (2001) provide evidence based on industry level data for the cost channel, and Christiano et al. (2001) have incorporated a cost channel into an aggregate model estimated using U.S. aggregate data. Besides providing additional empirical evidence for a cost channel of monetary policy, we explore its implications for monetary policy trade-offs, the objectives of monetary policy, and the effects of shocks on the economy under optimal discretionary and commitment policies.

We derive the appropriate welfare-based loss function that should be the policy-maker's objective in a cost-channel economy and show it is possible to express the loss function in terms of the gap between output and a measure of potential output that is invariant to assumptions on monetary policy in the flexible-price equilibrium. As a consequence, the optimal policy implications can be directly compared with standard new Keynesian results. As we show, the presence of a cost channel alters these standard policy conclusions in important ways.

If a cost channel exists, *any* shock to the economy—whether a productivity, government spending, or preference shock—generates a trade-off between stabilizing inflation and stabilizing the output gap. In the standard new Keynesian model of Clarida et al. (1999), the optimal response to such shocks guarantees that neither inflation nor the output gap deviate from their flexible-price equilibrium values. In contrast, these shocks lead to inflation and output gap fluctuations under optimal policy (either commitment or discretion) when a cost channel is present. An adverse productivity shock, for example, leads to a fall in the output gap and a rise in inflation under optimal policy. Hence, if we assume the central bank behaves optimally, observing a rise in the inflation rate does not imply that a cost push-shock has hit the economy; an adverse productivity shock would generate the same inflation behavior. Conversely, observing a positive productivity shock coupled with constant inflation would imply that the central bank is *not* following the optimal policy.

We also show that the optimal policy does not fully insulate the output gap and inflation from fiscal shocks. This finding is independent of the presence of the cost channel, and it parallels the results of Khan et al. (2003) and Benigno and Woodford (2004). A common conclusion from many recent analyses of monetary policy is that shocks to the expectational *IS* curve should be neutralized so that they do not affect the output gap. We show that when the objective function is derived as a second order approximation to the representative agent's utility function, neutralizing *IS* shocks arising from fiscal policy is not optimal, because such shocks affect welfare even when the output gap and inflation remain equal to zero.

The rest of the paper is organized as follows. In Section 2, the model is set out and the equilibrium under flexible prices and under sticky prices is derived. Section 3 estimates a new Keynesian inflation–adjustment equation and tests for the presence of a cost channel. We find that we cannot reject the hypothesis that a cost channel is present. Hence, in Section 4 we analyze the consequences of the cost channel for optimal policy. We derive a second order approximation to the utility of the representative agent and use this to define optimal policy objectives. Then, we analyze optimal policy under discretion and under commitment and show how previous results are modified when monetary policy operates through the cost channel. Finally, conclusions are contained in Section 5.

2. The basic model

Several theoretical models can generate a cost-side effect of monetary policy. Models which incorporate a balance-sheet or credit channel of monetary policy imply movements in interest rates directly affect firms' ability to produce (Bernanke and Gertler, 1989). Christiano and Eichenbaum (1992) introduce the cost of working capital into the production side of their model, assuming that factors of production have to be paid before the proceeds from the sale of output are received. Barth and Ramey (2001), using data for trade credit from the *U.S. Flow of Funds*, report that over the period 1995–2000 net working capital (inventories plus trade receivables, net of trade payables) averaged 11 months of sales, an amount comparable to the investment in fixed capital.

The basic framework we use to illustrate the cost channel is a cash-in-advance model with sticky prices that is similar to the model employed by Christiano et al. (2001). We simplify their model by ignoring capital and habit persistence in consumption. In order to capture the role of demand shocks, we introduce both a taste shock to the marginal utility of consumption and stochastic shocks to government purchases.

The model economy consists of households, firms, the government, and financial intermediaries interacting in asset, goods, and labor markets. The goods market is characterized by monopolistic competition, and the adjustment of prices follows the standard treatment based on Calvo (1983). Derivations of the basic new Keynesian model can be found in Woodford (2003) and Walsh (2003a). We focus here on those aspects of the model that differ from the standard specification.

The preferences of the representative household are defined over a composite consumption good C_t, a taste shock ξ_t, and leisure $1 - N_t$. Households maximize the expected present discounted value of utility

$$\mathrm{E}_t \sum_{i=0}^{\infty} \beta^i \left[\frac{\xi_{t+i} C_{t+i}^{1-\sigma}}{1-\sigma} - \chi \frac{N_{t+i}^{1+\eta}}{1+\eta} \right]. \tag{1}$$

The composite consumption good consists of differentiated products produced by monopolistically competitive final goods producers (firms). There is a continuum of such firms of measure 1. C_t is defined as

$$C_t = \left[\int_0^1 c_{jt}^{(\theta-1)/\theta} \, \mathrm{d}j \right]^{\theta/(\theta-1)}, \quad \theta > 1,$$

where c_{jt} is the consumption of the good produced by firm j. Given prices p_{jt} for the final goods, this preference specification implies the household's demand for good j and the aggregate price index P_t are

$$c_{jt} = \left(\frac{p_{jt}}{P_t}\right)^{-\theta} C_t,$$

$$P_t = \left[\int_0^1 p_{jt}^{1-\theta}\,\mathrm{d}j\right]^{1/(1-\theta)}. \tag{2}$$

Households enter period t with cash holdings of M_t. They receive their wage income paid as cash at the start of the period. They use this cash to make deposits D_t at the financial intermediary. Their remaining cash balances of $M_t + W_tN_t - D_t$ are available to purchase consumption goods subject to a cash-in-advance constraint that takes the form $P_tC_t \leqslant M_t + W_tN_t - D_t$. At the end of the period, households receive profit income from the financial intermediary and firms and the principle plus interest on their deposits at the intermediary. Consequently, cash carried over to period $t+1$ is

$$M_{t+1} = M_t + W_tN_t - D_t - P_tC_t + R_tD_t + \Pi_t - T_t,$$

where R_t is the gross nominal interest rate, Π_t is equal to aggregate profits from intermediaries and firms, and T_t are (lump-sum) taxes.[1]

In addition to the demand functions for the individual goods, the following first order conditions must hold in an equilibrium with a positive nominal interest rate:

$$\xi_t C_t^{-\sigma} = \beta \mathrm{E}_t\left(\frac{R_tP_t}{P_{t+1}}\right)\xi_{t+1}C_{t+1}^{-\sigma}, \tag{3}$$

$$\frac{\chi N_t^{\eta}}{\xi_t C_t^{-\sigma}} = \frac{W_t}{P_t}, \tag{4}$$

$$P_tC_t = M_t + W_tN_t - D_t. \tag{5}$$

Equilibrium in the goods market requires that $Y_t = C_t + G_t$, where G_t are government purchases. We assume the government purchases individual goods in the same proportions as households and that aggregate government purchases are proportional to output; $G_t = (1-\gamma_t)Y_t$, where γ_t is stochastic and bounded between zero and one. The aggregate resource constraint then takes the form $Y_t = C_t + G_t = C_t + (1-\gamma_t)Y_t$, or $C_t = \gamma_tY_t$.

Following the literature on staggered price setting, we adopt a Calvo specification in which the probability a firm optimally adjusts its price in each period is given by $1-\omega$. The fraction ω of firms that do not optimally adjust simply update their previous price by the steady-state inflation rate. If firm j sets its price at time t, it will do so to maximize expected profits, subject to the demand curve it faces, given by (2), and a CRS production technology $y_{jt} = A_tN_{jt}$, where y_{jt} is the total demand for good j by the household and government sectors and N_{jt} is employment by firm j in period t. A_t is a mean one stochastic aggregate productivity factor. The firm must borrow an amount W_tN_t from intermediaries at the gross nominal interest rate R_t, so the nominal cost of labor is R_tW_t. The real marginal cost is the same for all firm and equal to

$$\varphi_t \equiv \frac{R_tw_t}{A_t} = R_tS_t, \tag{6}$$

[1]The flexible and sticky price equilibrium equations relevant for the optimal monetary policy problem are unchanged if money is introduced through a money-in-the-utility-function rather than a cash-in-advance framework, provided firms have to borrow from the financial intermediary to pay their wage bill.

where S_t is labor's share of income and $w_t = W_t/P_t$ is the real wage. When prices are flexible, real marginal cost is equal to the inverse of the (constant) mark up $\Phi \equiv \theta/(\theta-1) > 1$:

$$\frac{R_t w_t}{A_t} = \frac{\theta - 1}{\theta}. \tag{7}$$

As is well known (see Galí and Gertler, 1999; Sbordone, 2002), this model leads to an inflation–adjustment equation of the form

$$\pi_t = \beta \mathrm{E}_t \pi_{t+1} + \kappa \hat{\varphi}_t, \tag{8}$$

where π_t is the deviation of inflation around the steady-state rate of $\bar{\pi}$ and $\hat{\varphi}_t$ is the percentage deviation of real marginal cost around its steady-state value of $(\theta-1)/\theta$. (A hat ˆ notation will be used to denote percentage deviations around steady-state values.) The parameter κ is given by $\kappa = (1-\omega)(1-\omega\beta)/\omega$.

The intermediary receives deposits and a cash injection X_t from the monetary authority. These funds are lent to firms at a gross nominal interest rate R_t. Intermediaries operate costlessly in a competitive environment, so profits in the intermediary industry are $R_t(D_t + X_t) - R_t D_t = R_t X_t = \Pi_t^i$. Letting G_{t+1} denote the gross growth rate of money from t to $t+1$, the cash injection can be expressed as $X_t = (M_{t+1} - M_t) = (G_{t+1} - 1)M_t$, and equilibrium in the market for loans implies that $W_t N_t^{\mathrm{d}} = D_t + X_t$, where N_t^{d} is aggregate labor demand by firms.

2.1. *The flexible-price equilibrium*

The flexible-price equilibrium is obtained by jointly solving Eqs. (4) and (7), using the production function and the aggregate resource constraint.[2] In the flexible-price equilibrium, denoted by the superscript f, firms equate the real wage, include interest costs, to the marginal product of labor divided by the markup:

$$R_t^{\mathrm{f}} w_t^{\mathrm{f}} = \frac{A_t}{\Phi}.$$

Households equate the real wage to the marginal rate of substitution between leisure and consumption:

$$\frac{\chi N_t^{\eta}}{\xi_t C_t^{-\sigma}} = w_t^{\mathrm{f}}.$$

Using the aggregate production function, $Y_t = A_t N_t$, the resource constraint, $C_t = \gamma_t Y_t$, and the labor market equilibrium condition gives the flexible-price solution for Y_t^{f}:

$$Y_t^{\mathrm{f}} = \left[\frac{\xi_t \gamma_t^{-\sigma} A_t^{1+\eta}}{\chi \Phi R_t^{\mathrm{f}}}\right]^{1/(\sigma+\eta)}. \tag{9}$$

Eq. (9) steady-state level of output is

[2] Details on the derivations of all results can be found in an Appendix, available at http://econ.ucsc.edu/~walshc/.

$$\bar{Y} = \left[\frac{\bar{\gamma}^{-\sigma}}{\chi \Phi \bar{R}}\right]^{1/(\sigma+\eta)}, \tag{10}$$

where an over bar denotes a steady-state value. Expressed in terms of percentage deviations around the steady-state, the flexible-price equilibrium output level is given by

$$\hat{Y}_t^{\mathrm{f}} = \left(\frac{1}{\sigma+\eta}\right)[(1+\eta)\hat{A}_t - \sigma\hat{\gamma}_t + \hat{\xi}_t - \hat{R}_t^{\mathrm{f}}]. \tag{11}$$

When only productivity disturbances are present, as in most new Keynesian models, Eq. (11) reduces to $\hat{Y}_t^{\mathrm{f}} = (1+\eta)\hat{A}_t/(\sigma+\eta)$. In the present model, the flexible-price output level is also affected by fiscal shocks ($\hat{\gamma}_t$), taste shocks ($\hat{\xi}_t$), *and* the nominal interest rate. Both fiscal and taste shocks would affect $\hat{Y}_t^{\mathrm{f}}$ even in the absence of a cost channel because they affect labor supply. The resource constraint implies that $\hat{C}_t = \hat{\gamma}_t + \hat{Y}_t$. A positive $\hat{\gamma}_t$ increases the share of output going to consumption; this lowers the marginal utility of consumption and reduces household labor supply. As a consequence, flexible-price output falls. At the same time, if $\hat{\gamma}$ shocks are transitory, consumption rises relative to future consumption, so the equilibrium real interest rate must fall. The fact that output and consumption move in opposite directions in response to a fiscal shock in the flexible price equilibrium contrasts with the situation with either a productivity shock or a taste shock. For example, a positive taste shock $\hat{\xi}_t$ increases the marginal utility of consumption and therefore increases labor supply; flexible-price output and consumption both rise.

Because of the cost channel, flexible-price output is not independent of the nominal rate of interest. A rise in the nominal interest reduces labor demand, reducing the equilibrium level of flexible-price output. The effects of the cost channel, fiscal shocks, and taste shocks on output operate through their impact on labor supply. In the case of an inelastic labor supply (the limit as $\eta \to \infty$), neither $\hat{R}$, $\hat{\gamma}$ nor $\hat{\xi}_t$ affect Y_t^{f}.

Even with flexible prices, output is distorted by the presence of monopolistic competition, by a positive nominal rate of interest, and by the wedge between consumption and output generated by the fiscal variable. The first of these distortions would be eliminated if $\Phi = 1$; the second distortion would be eliminated if the nominal interest rate were zero ($R = 1$). However, even if $R = \Phi = 1$, the resulting output level differs from the level chosen by a social planner, because private households do not internalize the effects of higher output on government spending that is implied by assuming G_t is proportional to Y_t. Let $\tilde{Y}_t = [\xi_t \gamma_t^{-\sigma} A_t^{1+\eta}/\chi]^{1/(\sigma+\eta)}$ be the output level under flexible prices when $R = \Phi = 1$. The fully efficient level of output can be shown to equal

$$Y_t^{\mathrm{e}} = \left[\frac{\xi_t \gamma_t^{1-\sigma} A_t^{1+\eta}}{\chi}\right]^{1/(\sigma+\eta)} = \gamma_t^{1/(\sigma+\eta)}\tilde{Y}_t < \tilde{Y}_t. \tag{12}$$

Government purchases, and therefore taxes, increase with output, but private agents do not account for these changes in deciding on labor supply and consumption. As a result, equilibrium output, in the absence of the distortions from imperfect competition and a positive nominal interest rate, is too high.[3]

[3]Bob King has pointed out to us that an optimal fiscal policy, even in the presence of lumpsum taxes, is to levy an income tax at the rate $\gamma_t - 1$ that "undoes" the effect of γ_t on the level of output.

2.2. Equilibrium with sticky prices

When prices are sticky ($\omega > 0$), inflation adjustment is given by Eq. (8). The difference between the model developed here and that of Galí and Gertler (1999) is that, from (6), real marginal cost now depends on the nominal interest rate:

$$\hat{\varphi}_t \approx \hat{R}_t + \hat{s}_t,$$

where $\hat{s}_t = \hat{w}_t + \hat{n}_t - \hat{y}_t$ is the log deviation of labor's share of output around the steady-state and $\hat{R}_t$ is the percentage point deviation of the nominal interest rate around its steady-state value. Hence, in the presence of a cost channel,

$$\pi_t = \beta \mathrm{E}_t \pi_{t+1} + \kappa(\hat{R}_t + \hat{s}_t). \tag{13}$$

The linearized versions of (3) and (4) can be used to express the sticky-price model in terms of the following two equations involving the gap between output and the flexible-price output level, a nominal interest rate gap, and a real interest rate gap:

$$\hat{Y}_t - \hat{Y}_t^{\mathrm{f}} = \mathrm{E}_t(\hat{Y}_{t+1} - \hat{Y}_{t+1}^{\mathrm{f}}) - \left(\frac{1}{\sigma}\right)[(\hat{R}_t - \mathrm{E}_t\pi_{t+1}) - \hat{r}_t^{\mathrm{f}}], \tag{14}$$

$$\pi_t = \beta \mathrm{E}_t \pi_{t+1} + \kappa(\sigma + \eta)(\hat{Y}_t - \hat{Y}_t^{\mathrm{f}}) + \kappa(\hat{R}_t - \hat{R}_t^{\mathrm{f}}), \tag{15}$$

where $\hat{r}_t^{\mathrm{f}}$ is the flexible-price real interest rate.[4]This two equation system differs from the standard new Keynesian model due to the presence of the nominal interest rate gap $\hat{R}_t - \hat{R}_t^{\mathrm{f}}$ in the inflation adjustment equation.

Before exploring the policy implications of the model further, we first turn to the aggregate empirical evidence for the cost channel.

3. Empirical evidence

In the econometric estimate of the cost channel, we generalize the model by assuming the production function for the monopolistically competitive firm j is

$$Y_t(j) = A_t\ K_t(j)^{\alpha_k}\ N_t(j)^{(1-\alpha_k)}, \quad 0 < \alpha_k < 1, \tag{16}$$

where A_t is the technology level, K_t capital, and N_t labor. Real marginal costs will now differ across firms if their production levels differ. Sbordone (2002) shows that inflation can be related to average real marginal cost according to

$$\pi_t = \beta \mathrm{E}_t \pi_{t+1} + \tilde{\kappa}\hat{\varphi}_t, \tag{17}$$

where $\tilde{\kappa} = \tau(1-\omega)(1-\beta\omega)/\omega$, $\tau \equiv (1-\alpha_k)/[1+\alpha_k(\theta-1)]$, and φ_t is given by labor's average share of income divided by $1-\alpha_k$. If the cost channel is introduced, firm j faces a total nominal production cost of $R_t W_t N_t(j) + R_t^k K_t(j)$. The inflation dynamics are still given by Eq. (17) and are a function of average real marginal cost defined as

[4]While the direct effect of an increase in the nominal interest rate is to increase inflation, the negative effect operating through output dominates. Conditional on expected inflation, $\partial\pi_t/\partial\hat{R}_t = \kappa - \kappa(\sigma+\eta)/\sigma = -\kappa\eta/(\sigma+\eta) \leqslant 0$, so that a rise in $\hat{R}_t$ reduces inflation.

$$\varphi_t = \frac{R_t W_t / P_t}{MPN_t} = \frac{R_t S_t}{(1-\alpha_k)}, \tag{18}$$

which implies, as before, that $\hat{\varphi}_t = \hat{R}_t + \hat{s}_t$.

We estimate Eq. (17) for the U.S. over the sample 1960:1–2001:1 using quarterly data. The econometric specification nests the definition of marginal cost given by (18) and allows a test of the hypothesis that movements in the nominal interest rate affect inflation dynamics via the cost channel. The estimation procedure follows Galí and Gertler (1999) and Galí et al. (2001). We obtain estimates of the deep parameters ω and β conditional on α_k and θ. As in Galí et al. (2001), we assume a labor share of $\frac{2}{3}$ and an average markup of 1.1 (which implies a value of 11 for θ).

We can rewrite (17) in terms of realized variables to obtain

$$\pi_t = \beta\pi_{t+1} + \tilde{\kappa}\hat{\varphi}_t + \zeta_t,$$

where ζ_t is a linear combination of the forecast error $\chi_t = -\beta[\pi_{t+1} - \mathrm{E}_t(\pi_{t+1})]$ and a random variable u_t. If u_t is taken to represent a measurement error, it is reasonable to expect it to have an i.i.d. distribution. We will later address the issue of alternative interpretations for u_t.

Let $\mathbf{z}_t$ be a vector of variables within firms' information set Ω_t that are orthogonal to ζ_t. Then (17) implies the orthogonality condition

$$\mathrm{E}_t[(\pi_t - \tilde{\kappa}\hat{\varphi}_t - \beta\pi_{t+1})\mathbf{z}_t] = 0.$$

If we express the orthogonality condition in terms of the deep parameters, and use the definition of real marginal cost (18), we can write a testable equation, which nests the case of the baseline pricing model and the case of the cost channel model, as

$$\mathrm{E}_t\{(\omega\pi_t - [(1-\omega)(1-\beta\omega)\tau](\hat{s}_t + \alpha\hat{R}_t) - \omega\beta\pi_{t+1})\mathbf{z}_t\} = 0. \tag{19}$$

For $\alpha = 0$, (19) gives the standard Calvo pricing model, tested in Galí et al. (2001). To find empirical support for the baseline cost channel model with the wage bill paid in advance, we should expect estimates of α to be not significantly different from 1.[5] Given our identifying assumptions and the orthogonality condition (19) we obtain estimates of α, β, and ω using a GMM estimator.

3.1. Model estimates

Our instrument vector $\mathbf{z}_t$ includes four lags of unit labor costs, GDP deflator inflation, a commodity price index inflation, the term spread, the nominal interest rate, wage inflation, and a measure of the output gap.[6] This vector $\mathbf{z}_t$ is labeled 'instrument set A' in the table.

[5] Our specification assumes firms must pay their entire wage bill at the start of the period. If workers receive a fraction $\phi < 1$ of their wages at the start of the period, Eq. (13) becomes $\pi_t = \beta\mathrm{E}_t\pi_{t+1} + \kappa(\phi\hat{R}_t + \hat{s}_t)$. This specification would justify estimates of $\alpha < 1$. However, when $\phi < 1$, firms pay the fraction ϕ of the interest tax on wages while households pay the remainder. As a consequence, the labor market equilibrium condition used to express marginal cost in terms of an output gap is unaffected by the value of ϕ and (14) and (15) do not change. Therefore, our results on optimal monetary policy in Section 4 are unaffected.

[6] This is the same set of instruments used by Galí and Gertler (1999), except for the addition of the nominal interest rate. Also, we use the Hodrick–Prescott filter measure of output gap rather than detrended output since the former can far better accommodate the surge in potential output during the second half of the 1990s. The results do not change significantly using the Galí and Gertler (1999) set of instruments.

Table 1
Estimates of the new Phillips curve

	ω	β	α	H_0: $\alpha = 1$	D-test	Hansen test
Instrument set A *Specification* (1)						
Restricted	0.512 (0.026)	0.895 (0.027)	0			
Unrestricted	0.543 (0.036)	0.850 (0.027)	1.276 (0.496) [0.010]	0.311 [0.576]	13.659 [0.000]	11.059 [0.988]
Instrument set B *Specification* (1)						
Restricted	0.546 (0.047)	0.921 (0.033)	0			
Unrestricted	0.611 (0.0612)	0.879 (0.034)	1.915 (1.210) [0.114]	0.572 [0.449]	7.240 [0.007]	8.226 [0.60]
Instrument set A *Specification* (2)						
Restricted	0.773 (0.056)	0.970 (0.017)	0			
Unrestricted	0.802 (0.048)	0.905 (0.021)	11.831 (6.040) [0.050]	3.215 [0.072]	58.52 [0.000]	10.696 [0.991]
Instrument set A *Spec.* (1)–*Recursive* GMM						
Restricted	0.476 (0.026)	0.93 (0.025)	0			
Unrestricted	0.547 (0.038)	0.860 (0.024)	1.239 (0.51) [0.016]	0.216 [0.641]		10.940 [0.989]

Note: GMM estimates of the structural parameters of (13). Newey–West corrected standard errors in brackets, *p*-values in square brackets. The null hypothesis for the D-test is H_0: $\alpha = 0$. Data sample is 1960:Q1 to 2001:Q1. Instrument set A includes four lags of: nonfarm business sector real unit labor cost, HP-filtered output gap, GDP deflator inflation, the CRB commodity price index inflation, 10 year–3 month U.S. government bond spread, nonfarm business sector hourly compensation inflation, 3-month T-bill rate. Instrument set B includes: two lags of nonfarm business sector real unit labor cost, HP-filtered output gap, nonfarm business sector hourly compensation inflation, and four lags of GDP deflator inflation and 3-month T-bill rate. All data supplied by the Bureau of Labor Statistics, the Bureau of Economic Analysis, the Federal Reserve System FRED database. Specification (1) uses orthogonality condition (19). Specification (2) uses orthogonality condition (20). Unless otherwise specified, the results report two-stages GMM estimates.

Table 1 reports the estimates using a nonlinear instrumental variables two-stage GMM estimator and the specification of the orthogonality condition as in Eq. (19). All standard errors are Newey–West corrected to take into account residual serial correlation.

The estimates for ω and β are reasonably close in the restricted ($\alpha = 0$) and unrestricted models, and also close to the Galí and Gertler (2001) estimates of 0.475 and 0.837. The implied estimate of $\tilde{\kappa}$ is positive and significant, and the implied average duration of posted price is between two and three quarters in both cases. When α is not constrained to 0, its point estimate of 1.276 is not significantly different from 1, as verified by a Wald test of the null $H_0 = 1$. The estimate of α has a higher standard error than the estimates of β and ω, yet it is significant at the 1% confidence level when the significance is tested with the Wald statistic. The difference between the values of the maximized criterion function for the restricted and unrestricted model can be used to perform the equivalent of a likelihood ratio test for the null hypothesis that $\alpha = 0$. This test, known in the literature as a D-test (see Matyas, 1999), rejects the null at a p-value below 0.1%. The Hansen test confirms that we cannot reject the over identifying restrictions, although it is well known that this test has low power against model misspecifications.

GMM guarantees a consistent estimate of the unknown parameter vector but not an unbiased estimate. Small sample bias of GMM estimators can be large, and it is not obvious which estimator is appropriate in different situations (see Florens et al., 2001).

A first issue relevant for the small sample properties of GMM estimators is the choice of instruments. While asymptotically any subset $\mathbf{z}_t \in \Omega_t$ should give the same GMM estimates, this is not necessarily true in small samples. Kocherlakota (1990) and Tauchen (1986) suggest that increasing the number of instruments can increase the bias of the estimates while reducing its variance. The instrument relevance for the results reported in Table 1 has been checked by running F-tests to verify the predictive power of the instruments. Other test criteria, like Theil's U-test and sequential elimination of instruments using the correlation matrix, would lead over some samples to a different instrument set. Table 1 also reports the estimation results for the instrument set used in Galí et al. (2001), to which four lags of the nominal interest rate are added. This smaller $\mathbf{z}_t$ vector, labeled 'instrument set B' in the table, includes: two lags of the unit labor costs, wage inflation, a measure of the output gap, and four lags of GDP deflator inflation and the nominal interest rate. The difference between the unrestricted and restricted model estimates of ω increases relative to the previous estimate. Using the new instrument set, the estimate of α has a p-value of only 11%. The D-test though can reject the hypothesis that $\alpha = 0$ at a confidence level below 1%. A serially correlated cost-push shock u_t may explain the sensitivity of the estimates to the choice of instrument set.

A second issue related to the nonlinear GMM small sample bias is the estimates' sensitivity to the orthogonality condition specification. Table 1 also reports estimates for the specification:

$$\mathrm{E}_t\{(\pi_t - [(1-\omega)(1-\beta\omega)\tau\omega^{-1}](s_t + \alpha\hat{R}_t) - \beta\pi_{t+1})\mathbf{z}_t\} = 0. \tag{20}$$

With this specification, the estimate of ω increases considerably in all cases, implying an average price duration between four and six quarters. The point estimate of α using the instrument set A is significant at the 5% confidence level but very high (11.831). The D-test also rejects the null hypothesis of $\alpha = 0$. Since the variance of the estimate is also fairly high, the hypothesis that $\alpha = 1$ can be rejected at the 5% confidence level, but not at the 10% level.

A third issue, the choice of the GMM estimator itself, has been widely explored in the literature as a way to try to correct for the small sample bias. The standard GMM estimator minimizes the scalar $g_T(\vartheta)W_T g_T(\vartheta)$ where $g_T(\vartheta)$ is the sample equivalent of the orthogonality condition and W is the GMM weighting. The optimal feasible estimator is obtained for $W_T = (\tilde{S}_T)^{-1}$ where $\tilde{S}_T$ is the estimate of the asymptotic covariance matrix. Usually an estimate for S_T is obtained from an initial IV estimate of ϑ. Hansen (1982) suggests an alternative approach: the parameters and the weighting matrix can be estimated recursively until $(\tilde{\vartheta}^{(i)} - \tilde{\vartheta}^{(i-1)})$ is smaller than a convergence criterion. This iterative GMM estimate has the same asymptotic distribution as the two-stage estimate.

Table 1 reports estimates of α using the orthogonality condition (19) and the iterative GMM procedure, which has the advantage of being independent with respect to $W_T^{(1)}$. Iterative estimates confirm the two-stage estimates when instrument set A is used. The α estimate is significant, and we cannot reject the null hypothesis that $\alpha = 1$.[7]

In summary, the empirical evidence is suggestive of a direct interest rate effect on inflation, consistent with the presence of a cost channel through which marginal cost depends on both real wages relative to marginal productivity and the nominal rate of interest. Given this evidence, we proceed in the following section to explore the policy implications of the cost channel.

4. Optimal monetary policy

In this section, we first show that the presence of the fiscal shock $\hat{\gamma}_t$ implies a wedge between the output gap $\hat{Y}_t - \hat{Y}_t^{\mathrm{f}}$ and the appropriate "welfare output gap" variable in the central bank's loss function. This conclusion is independent of the presence of a cost channel. Second, we derive optimal policies and show that the cost channel leads to policy trade-offs between the welfare-relevant output gap and inflation even in the absence of the ad hoc cost shock that is typically added to the new Keynesian model to generate such trade-offs.

Following Erceg et al. (2000) and Woodford (2003), we obtain our policy objective function by taking a second order approximation to the utility of the representative agent. Details are provided in an Appendix available from the authors.[8] It can be shown that the present discounted value of the utility of the representative household can be approximated by

$$\sum_{t=0}^{\infty} \beta^t \mathrm{U}_t \approx \bar{\mathrm{U}} - \Omega \sum_{t=0}^{\infty} \beta^t L_t,$$

where

$$L_t = \pi_t^2 + \lambda(\hat{Y}_t - \hat{Y}_t^{\mathrm{e}} - z^*)^2, \tag{21}$$

$$\hat{Y}_t^{\mathrm{e}} = \frac{(1+\eta)\hat{A}_t + \hat{\xi}_t + (1-\sigma)\hat{\gamma}_t}{\sigma + \eta}, \tag{22}$$

and z^* is the gap between the flexible-price steady-state equilibrium output and the efficient steady-state output level. Note that $\hat{Y}_t^{\mathrm{e}}$ is the log deviation around steady-state of the efficient output level given by (12) derived as the solution to the social planner's problem. The parameter λ in (21) is given by

$$\lambda = \left[\frac{(1-\omega)(1-\omega\beta)}{\omega}\right]\left(\frac{\sigma+\eta}{\theta}\right).$$

According to (21), the appropriate welfare gap measure in the policy maker's loss

[7] When instrument set B is used, the point estimate increases to 5.282 from the value 1.915 obtained with the two-stage GMM. But the estimate is now highly significant. The null of $\alpha = 1$ can be rejected at the 10% confidence level, but not at the 5% level.

[8] The approximation is based on the assumption that steady-state distortions are small in that sense that $1 - (\bar{\gamma}\Phi\bar{R})^{-1}$ is small.

function, $\hat{Y}_t - \hat{Y}^{e}_t - z^*$, differs from the gap between output and the flexible price equilibrium output level, $\hat{Y}_t - \hat{Y}^{f}_t$. The difference between these two gaps can be seen by writing the welfare gap as

$$\hat{Y}_t - \hat{Y}^{e}_t - z^* = (\hat{Y}_t - \hat{Y}^{f}_t) - \left(\frac{1}{\sigma+\eta}\right)(\hat{R}^{f}_t + \hat{\gamma}_t) - z^*. \tag{23}$$

The last term on the right, z^*, is the gap between the flexible price, steady-state output level and the efficient steady-state output level, and is equal to $(\bar{\gamma}\Phi\bar{R} - 1)/\bar{\gamma}\Phi\bar{R}(\sigma+\eta)$. It depends on the presence of monopolistic competition via the markup Φ, the fiscal tax $\bar{\gamma}$, *and* the monetary distortion generated by a nonzero average nominal rate of interest ($\bar{R} > 1$). Because our main focus is on stabilization policies, we will follow the literature in assuming that fiscal subsidies ensure these average efficiency distortions are eliminated so that $z^* = 0$. With $z^* = 0$, the welfare gap consists of two terms. The first term on the right, $\hat{Y}_t - \hat{Y}^{f}_t$, is the output gap expression that arises in the standard new Keynesian model. Marginal cost is proportional to $\hat{Y}_t - \hat{Y}^{f}_t$, and this same output gap also appears in the standard new Keynesian inflation equation. Hence in this model a policy designed to keep output equal to the flexible-price output level also succeeds in stabilizing inflation. The second term arises because of the inflation-tax distortions operating through the cost channel that depend on fluctuations in the nominal interest rate and the inefficiency associated with fluctuations in the fiscal variable due to the externality discussed in Section 2. Therefore in a cost channel model the policy instrument $\hat{R}^{f}_t$ cannot be adjusted to stabilize simultaneously inflation and the output gap. Moreover, because $\hat{\gamma}_t$ affects the wedge between the efficient level of output and the flexible-price output, even if prices are flexible or the central bank keeps $\hat{Y}_t = \hat{Y}^{f}_t$, it may be optimal to offset fluctuations in $\hat{\gamma}_t$ by allowing $\hat{Y}_t - \hat{Y}^{f}_t$ to fluctuate, despite this leading to inflation fluctuations.

From (11), we can define the output level which would obtain in the flexible-price equilibrium, conditional on the policy rule $\hat{R}^{f}_t = 0$ for all t, as[9]

$$\hat{Y}^{*}_t = \frac{(1+\eta)\hat{A}_t - \sigma\hat{\gamma}_t + \hat{\xi}_t}{\sigma+\eta} \tag{24}$$

and the welfare gap (23) becomes (with $z^* = 0$)

$$\hat{Y}_t - \hat{Y}^{e}_t = \hat{Y}_t - \hat{Y}^{*}_t - \left(\frac{1}{\sigma+\eta}\right)\hat{\gamma}_t.$$

This also means that we can re-express real marginal cost as

$$\hat{\varphi}_t = (\sigma+\eta)(\hat{Y}_t - \hat{Y}^{*}_t) + \hat{R}_t. \tag{25}$$

If we define $x_t \equiv \hat{Y}_t - \hat{Y}^{*}_t$ as our output gap—the gap between output and the flexible-price output under a constant nominal interest rate—the monetary policy problem can be written as

$$\max -\frac{1}{2}\,\mathrm{E}_t \sum_{t=0}^{\infty} \beta^t \left\{ \pi_t^2 + \lambda\left[x_t - \left(\frac{1}{\sigma+\eta}\right)\hat{\gamma}_t\right]^2 \right\} \tag{26}$$

subject to

[9] Note that $\hat{R}_t = 0$ corresponds to an interest rate peg in the flexible-price equilibrium, not a zero nominal interest rate.

$$x_t = \mathrm{E}_t x_{t+1} - \left(\frac{1}{\sigma}\right)(\hat{R}_t - \mathrm{E}_t \pi_{t+1}) + u_t \tag{27}$$

and

$$\pi_t = \beta \mathrm{E}_t \pi_{t+1} + \kappa(\sigma + \eta) x_t + \kappa \hat{R}_t, \tag{28}$$

where

$$u_t \equiv \left(\frac{1+\eta}{\sigma+\eta}\right)\left[(\mathrm{E}_t \hat{A}_{t+1} - \hat{A}_t) - \left(\frac{\eta}{\sigma}\right)(\mathrm{E}_t \hat{\xi}_{t+1} - \hat{\xi}_t) + \frac{\eta}{1+\eta}(\mathrm{E}_t \hat{\gamma}_{t+1} - \hat{\gamma}_t)\right] \tag{29}$$

is a composite, exogenous "demand" disturbance term that depends on productivity, taste, and fiscal shocks.

Under discretion, the first order conditions imply[10]

$$\pi_t = -\left(\frac{\lambda}{\kappa\eta}\right)\left[x_t - \left(\frac{1}{\sigma+\eta}\right)\hat{\gamma}_t\right]. \tag{30}$$

Because the nominal interest rate appears in (28), it is necessary to solve (27), (28) and (30) jointly to obtain the equilibrium. Thus, shocks appearing in the expectations *IS* equation will force the central bank to trade-off its inflation and welfare gap objectives, even in the absence of a standard cost shock in the inflation equation. In addition, as the first order condition illustrates, it will not be optimal to maintain zero inflation and a zero welfare gap in the face of fiscal shocks. Eq. (30) also highlights how the trade-off between output and inflation objectives is affected by the cost channel. In the standard case, the coefficient on x_t in the first order condition would be $\lambda/\kappa(\sigma+\eta) < \lambda/\kappa\eta$. Thus, with a cost channel, optimal policy will result in greater inflation variability for a given level of output gap variability. Intuitively, stabilizing inflation has become more costly; as $\hat{R}_t$ is increased, for example, x_t decreases, and this serves to reduce inflation, but the direct inflation effect of the rise in the nominal interest rate partly offsets the deflationary impact of tighter monetary policy. Because it is more costly (in terms of the output gap) to control inflation, equilibrium inflation variability will be higher.

To highlight further the role of the cost channel, consider the effects of productivity and taste shocks. These enter the equilibrium conditions through the definition of the *IS* disturbance u_t. In the absence of a cost channel, the nominal interest rate would not appear in (28). In this standard case, the nominal interest rate can be adjusted to neutralize fully the impact of productivity and taste shocks on the output gap and inflation; optimal policy in the face of productivity and taste shocks maintains inflation and the output gap at zero. Actual output moves in tandem with fluctuations in the flexible-price equilibrium output caused by productivity and taste shocks.

Now consider how this conclusion is altered in the presence of a cost channel. With $\hat{R}_t$ appearing in (28), the nominal interest rate cannot be used to insulate the output gap from productivity or taste shocks without causing fluctuations in the rate of inflation. The central bank will need to trade-off its output gap and inflation objectives. Consider the case of a productivity shock.[11] Assume the productivity shock follows an $AR(1)$ process given by $\hat{A}_t = \rho_a \hat{A}_{t-1} + a_t$ with $0 < \rho_a < 1$. A positive realization of $\hat{A}_t$ raises current output relative to future output, and the equilibrium real rate of interest must fall to induce a rise

[10] See the Appendix for details.

[11] The analysis of a taste shock would be exactly parallel.

in current consumption relative to future consumption. This corresponds to a negative realization of u_t. If the nominal interest rate is reduced to maintain a zero output gap, inflation falls via the cost channel. To limit this decline in inflation, the optimal policy lets output rise above the flexible-price equilibrium level. Thus, actual output expands more than the flexible-price equilibrium output level in response to a positive productivity shock. Under an optimal discretionary policy, the output gap and inflation return gradually to their steady-state value. Under commitment, policy induces more inertia (Woodford, 2003) and the inflation rate, after first falling below zero, rises above zero, ensuring that the price level is stationary. The output gap responds positively to the productivity shock, as under discretion, but under commitment it then rises further to generate the positive rates of inflation needed to return the price level to its original level.

The responses of output and inflation under the optimal discretionary policy in the face of a positive productivity shock appear similar to the experience of the U.S. in the 1990s—in the face of a positive productivity shock, output expanded above most estimates of trend growth, while inflation declined. The impact of u_t on inflation is increasing in λ; if the central bank places no weight on output gap stabilization ($\lambda = 0$), then it adjusts the nominal interest rate to offset the impact of output movements on inflation, keeping inflation equal to zero. When output gap stabilization is also desirable, the central bank must accept some fluctuation in both π_t and x_t in the face of u_t disturbances.

The situation is more complicated for the case of fiscal shocks, as these affect u_t and alter the welfare output gap directly. As in the models of Khan et al. (2003) and Benigno and Woodford (2004), the fiscal variable generates a wedge between the output gap and what we have called the welfare gap. In the absence of the cost channel, the impact of $\hat{\gamma}$ on u and aggregate demand could be neutralized to keep inflation and the output gap at zero. However, this would cause the welfare gap to move with the fiscal shock. To reduce fluctuations in welfare, the optimal policy would allow both inflation and the output gap to deviate from zero. A rise in government spending (a negative γ) has effects similar to a negative cost shock in a standard new Keynesian model; maintaining a zero output gap so that inflation also remains at zero causes a rise in the welfare gap.[12] To limit the rise in the welfare gap, the output gap must fall, and optimal policy will trade-off some decrease in inflation to dampen the movement in the welfare gap. Thus, while the fiscal shock increases the flexible-price equilibrium level of output through the effect of higher taxes on labor supply, actual output and employment rise less, allowing the output gap to fall. Since $\hat{C}_t = \hat{\gamma}_t + \hat{Y}_t = \hat{\gamma}_t + \hat{Y}_t^* + x_t$, the fall in x_t reinforces the negative realization of $\hat{\gamma}_t$, increasing the variability of consumption. These effects under the optimal monetary policy are similar to those obtained by Khan et al. (2003), who find that optimal policy increases consumption variability in the face of fiscal shocks.

To illustrate the response to fiscal shocks under optimal discretionary and commitment policies, we calibrate the model and solve it numerically. The basic parameter values we use are fairly standard. We set $\sigma = 1.5$, and $\eta = 1$. The discount factor, β, is set equal to 0.99, appropriate for interpreting the time interval as one quarter. The value of 0.75 for ω is consistent with the empirical findings of Galí and Gertler (1999) and those reported in Section 3. A value of 11 for θ implies a steady-state markup of 1.1. For the impulse responses, we report the impact of a 1-unit innovation to $\hat{\gamma}$, and we allow the

[12]Recall that the welfare gap can be written as $x_t - (1/(\sigma + \eta))\gamma_t$.

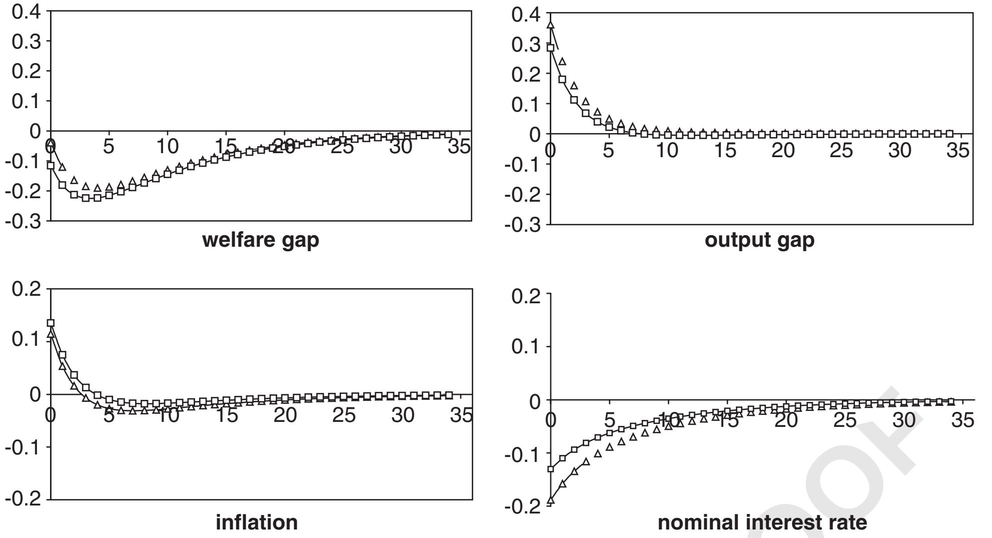

Fig. 1. Response to a fiscal shock under optimal commitment with (triangles) and without (squares) the cost channel.

shock to be highly serially correlated, $\rho_\gamma = 0.9$.[13] Optimal policy also depends on the value of λ. Given these parameter values, the underlying theory implies $\lambda = (1-\beta\omega)(1-\omega)(\sigma+\eta)/(\omega\theta) = 0.0195$. In most of the monetary policy literature, larger values of λ are commonly employed. For example, McCallum and Nelson (2000), Jensen (2002), and Walsh (2003b) set $\lambda = 0.25$. Since the qualitative results are similar, we only report results for $\lambda = 0.25$.

The responses of the welfare gap, the output gap, inflation, and the nominal interest rate to a positive γ_t shock under the optimal commitment policy, with and without the cost channel are shown in Fig. 1. Recall that a positive innovation to γ_t corresponds to a negative shock to government spending. For a given level of output, this implies consumption rises and households reduce their labor supply; as a consequence, the efficient and flexible-price levels of output falls. Under the optimal commitment policy, actual output also falls but by less than $\hat{Y}^*$ does, so the output gap rises. Inflation increases, while the welfare gap falls.

While the cost channel does not materially affect the basic responses to a fiscal shock, the nominal interest rate does fall more when a cost channel is present, leading to a larger rise in the output gap. This serves to limit the fall in the welfare gap. Given that the efficient level of output drops on impact and then increases back to the steady-state, a positive and decreasing output gap requires a fall in the real interest rate. Under commitment, this is achieved primarily by a fall in the nominal interest rate $\hat{R}_t$.

Under discretion, the situation is somewhat different, as shown in Fig. 2. The output gap responds less than under commitment (implying output falls more since $\hat{Y}^{\mathrm{f}}$ is independent

[13] The autocorrelation coefficients play a different role from the one outlined in Clarida et al. (1999). The *IS* curve shock u_t is a function of the differences $(\mathrm{E}_t\hat{A}_{t+1} - \hat{A}_t)$, $(\mathrm{E}_t\hat{\xi}_{t+1} - \hat{\xi}_t)$, $(\mathrm{E}_t\hat{\gamma}_{t+1} - \hat{\gamma}_t)$. Larger values of ρ map into a smaller shock u_t.

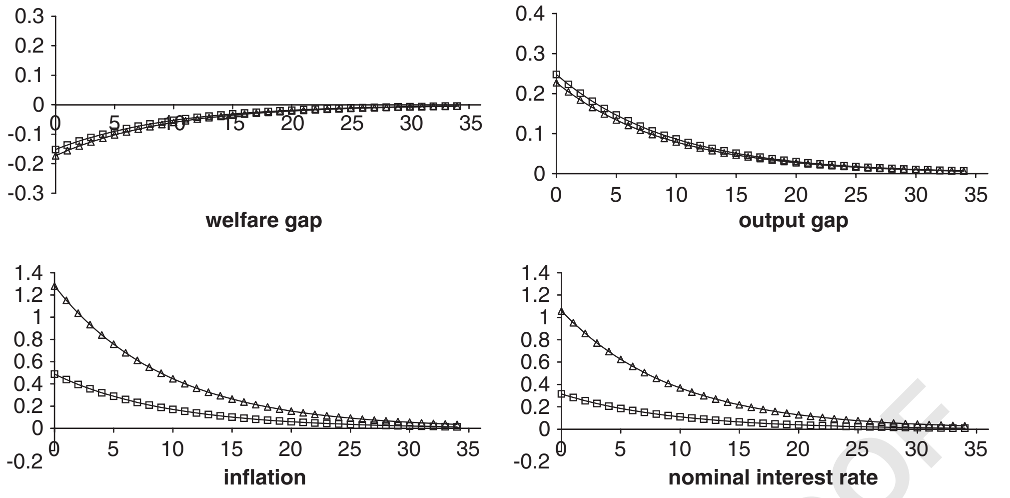

Fig. 2. Response to a fiscal shock under optimal discretion with (triangles) and without (squares) the cost channel.

of the policy regime). This means the gap falls more in the presence of the cost channel than when it is absent. The major difference, however, occurs in the behavior of inflation, which is much more sensitive to the $\hat{\gamma}$ shock under discretion than under commitment. This reflects the poorer output gap–inflation trade-off faced under discretion. Because the central bank cannot commit to producing a future deflation, it is less able to stabilize current inflation. Under discretion, a prolonged rise in inflation occurs following a persistent decline in government demand. Because this increases expected inflation, the nominal interest rate actually *increases* in response to the positive fiscal shock even though the real interest rate falls. The existence of a cost channel has little effect on the response of either the welfare gap or the output gap. The primary impact of a cost channel is to produce much greater inflation movements due to the larger movements in the nominal rate of interest.

5. Conclusions

In the new Keynesian model that has become a standard framework for investigating monetary policy issues, policy operates on aggregate spending through an interest rate channel. For many purposes, the exact nature of the monetary policy transmission mechanism is unimportant—the critical factors for policy are the objective function of the central bank and the inflation–adjustment mechanism. The details of the channels through which interest rate changes affect spending are only relevant for determining the actual nominal interest rate behavior that is required to achieve the desired time paths of inflation and the output gap. In this paper, we have investigated the implications for optimal policy when monetary policy also affects the economy through a cost channel. If nominal interest rate movements directly affect real marginal cost, as the empirical evidence of Barth and Ramey (2001) and the evidence we reported in Section 3 suggest, then monetary policy directly affects the inflation–adjustment equation.

We derived the appropriate welfare-based loss function for the cost channel economy. The flexible-price level of output is not independent of monetary policy as in the standard model—therefore a reference 'potential output' for the economy is not uniquely defined. But since welfare can be expressed as a function of the gap between output and the level of output conditional on a constant interest rate policy, the policy-maker's loss can still be written in terms of inflation and a well-defined measure of an output gap.

Interest rate changes necessary to stabilize the output gap lead to inflation rate fluctuations when a cost channel is present. As a consequence, the output gap and inflation will fluctuate in response to productivity and demand disturbances even when the central bank is setting policy optimally. A positive productivity shock leads to a fall in inflation and a rise in the output gap under either optimal commitment or optimal discretionary. Thus, a period of above average productivity should also be associated with a rise in output above the flexible-price level (a rise in the output gap) and a decline in inflation.

Finally, we also showed that an optimal policy, either under commitment or discretion, does not stabilize the output gap and inflation in the face of fiscal shocks. This result holds regardless of whether a cost channel is present. In earlier analyses, an ad hoc demand shock was often added to the expectational *IS* curve, and optimal policy would always move the interest rate to ensure these shocks did not affect the output gap or inflation. When fiscal shocks alter the share of output available for consumption, stabilizing their impact on the output gap is not an optimal policy. Instead, a positive shock to government spending increases the flexible-price level of output. Under an optimal monetary policy, the output gap and inflation both fall, implying that it is optimal to ensure actual output rises less than the flexible-price level of output.

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