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ABSTRACT

Standard discussions of flexible inflation targeting as an optimal monetary policy abstract completely from the consequences of monetary policy for the government budget. But at least some of the countries now adopting inflation targeting have substantial difficulty in controlling fiscal imbalances, so that the additional strains resulting from strict control of inflation are of substantial concern, and some (notably Sims 2005) have argued that inflation targeting can even be counterproductive under some fiscal regimes. Here, therefore, we analyze welfare-maximizing monetary policy taking explicit account of the consequences of monetary policy for the government budget, and under a variety of assumptions about the nature of the fiscal regime.

The paper contrasts the optimal monetary policies under three alternative assumptions about fiscal policy: (i) the case in which little distortion is required to raise additional government revenue, and the fiscal authority can be relied upon to ensure intertemporal government solvency [the implicit assumption in standard analyses]; (ii) the case in which only distorting sources of revenue exist, but distorting taxes are adjusted optimally; and (iii) the case in which tax rates cannot be expected to change in response to a change in monetary policy [the problematic case emphasized by Sims]. In both of cases (ii) and (iii), it is optimal for monetary policy to allow the inflation rate to respond to fiscal developments (and the optimal responses to other shocks are somewhat different than in the classic analysis, which assumes case (I)). Nonetheless, optimal monetary policy can still be implemented through a form of flexible inflation targeting, and it remains critical, even in the most pessimistic case (case (iii)), that inflation expectations (beyond some very short horizon) not be allowed to vary in response to shocks.

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Since its adoption in Chile and elsewhere early in the 1990s, inflation targeting has become an increasingly popular approach to the the conduct of monetary policy worldwide. Most of the countries that have adopted inflation targeting judge the experiment favorably, at least thus far. In many countries the adoption of inflation targeting has been associated with reductions in both the average level and volatility of inflation. Inflation targeting has been especially successful in stabilizing inflation expectations,[1] as one might expect, given the emphasis that is typically given to a clear medium-term commitment regarding inflation (while temporary departures from the inflation target are allowed), and the typical increase in the degree of communication by inflation-targeting central banks with regard to the outlook for inflation over the next few years.

But is inflation targeting an approach to monetary policy that is equally suitable for all countries, regardless of the institutions that may exist in a given country, the disturbances to which a particular economy is subject, and the other policies that are pursued by that country's government? A question that would seem particulary worthy of discussion is how a country's *fiscal* policies might affect the suitability of inflation targeting as an approach to the conduct of monetary policy.

The fiscal consequences of commitment to an inflation target have largely been neglected in the theoretical literature that develops the case for inflation targeting.[2] Typically, the models used to analyze monetary stabilization policy abstract from the government's budget and dynamics of the public debt altogether, so that any fiscal effects of monetary policy decisions are tacitly assumed to be irrelevant. And it may be an acceptable simplification to proceed in this way, if one is choosing a policy for an economy with sound government finances, by which we mean one for which relatively non-distorting sources of revenue exist and the political will to maintain government solvency need never be doubted. But countries differ in the degree to which such an idealization of the circumstances of fiscal policy is realistic; and especially as inflation targeting becomes popular in developing countries which have recently had serious problems with inflation exactly because of their precarious government finances, one may wonder how safe it is to ignore the interrelation between monetary and fiscal policy choices.

[1] See, for example, the comparison of inflation expectations in IT and non-IT countries by Levin *et al.* (2004).

[2] See, for example, King (1997), Svensson (1997, 1999, 2003), Woodford (2003, chaps. 7-8), Walsh (2003, chap. 11), or Svensson and Woodford (2005) for canonical examples of the theoretical case for some version of inflation targeting as an optimal policy.

Indeed, a number of authors have suggested that the appropriateness of inflation targeting as a policy recommendation may depend critically on the nature of fiscal policy. For example, Fraga *et al.* (2003), in the context of a discussion of inflation targeting for developing countries, remark that "the success of inflation targeting ... requires the absence of fiscal dominance" (p. 383), and go on to stress that it is not only necessary that fiscal policy *be* sound in this respect, but also necessary that it be credible that it will continue to be. Their intent is not to suggest that inflation targeting not be adopted by developing countries, but rather to emphasize the importance of enacting credible fiscal reforms as well; but their insistence on the need for fiscal commitments that are not obviously present in many developing countries raises the question whether inflation targeting is not ill-advised in such countries.

Sims (2005) enunciates exactly this view. He argues that some countries' fiscal policies may make achievement of a target rate of inflation by the central bank *impossible,* in the sense that there exists no possible rational-expectations equilibrium in which the target is fulfilled, regardless of the conduct of monetary policy. He furthermore asserts that in such a case, *attempting* to target inflation may be not only doomed to frustration, but harmful, in that it leads to less stability (even less stability of the inflation rate) than could have been achieved through other policies. His essential argument is that if the fiscal regime ensures that primary budget surpluses are not (sufficiently) increased in response to a monetary tightening, then a policy intended to contain inflation — raising nominal interest rates sharply when inflation rises above the inflation target — may cause an explosion of the public debt, which ultimately requires even larger price increases than would have been necessary had the debt not grown. Examples of models in which "orthodox" monetary policies of this kind lead to explosive debt dynamics have been presented by Loyo (1999) and Blanchard (2005).

Our goal here is to analyze the character of an optimal monetary policy commitment under alternative assumptions about the character of fiscal policy, in order to determine to what extent an optimal policy will be similar to inflation targeting, and in particular to see to what extent the form of an optimal monetary policy rule depends on the nature of fiscal policy. In order to address these issues, we extend the framework used to analyze optimal monetary stabilization policy in Benigno and Woodford (2005a), to explicitly model debt dynamics and the conditions required for intertemporal government solvency, and also to treat the effects of tax distortions. We consider a variety of assumptions regarding the character of fiscal policy, including the kind of fiscal regime — under which there is no adjustment of the real primary budget surplus in order to prevent explosion of the public debt as a result of an increase in interest rates — that is at the heart of the Loyo and Blanchard examples of possible perverse effects of tight-money policies.

1 A Model with Non-Trivial Monetary and Fiscal Policy Choices

The model that we shall use for our analysis is a standard "New Keynesian" model of the tradeoffs involved in monetary stabilization policy, augmented to take account of tax distortions.[3]

1.1 The Model

The goal of policy is assumed to be the maximization of the level of expected utility of a representative household. In our model, each household seeks to maximize

$$U_{t_0} \equiv E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} \left[\tilde{u}(C_t; \xi_t) - \int_0^1 \tilde{v}(H_t(j); \xi_t) dj \right], \tag{1.1}$$

where C_t is a Dixit-Stiglitz aggregate of consumption of each of a continuum of differentiated goods,

$$C_t \equiv \left[\int_0^1 c_t(i)^{\frac{\theta}{\theta-1}} di \right]^{\frac{\theta-1}{\theta}}, \tag{1.2}$$

with an elasticity of substitution equal to $\theta > 1$, and $H_t(j)$ is the quantity supplied of labor of type j. Each differentiated good is supplied by a single monopolistically competitive producer. There are assumed to be many goods in each of an infinite number of "industries"; the goods in each industry j are produced using a type of labor that is specific to that industry, and also change their prices at the same time. The representative household supplies all types of labor as well as consuming all types

[3] Further details of the derivation of the structural equations of our model of nominal price rigidity can be found in Woodford (2003, chapter 3).

of goods. To simplify the algebraic form of our results, we restrict attention in this paper to the case of isoelastic functional forms,

$$\tilde{u}(C_t; \xi_t) \equiv \frac{C_t^{1-\tilde{\sigma}^{-1}} \bar{C}_t^{\tilde{\sigma}^{-1}}}{1-\tilde{\sigma}^{-1}},$$

$$\tilde{v}(H_t; \xi_t) \equiv \frac{\lambda}{1+\nu} H_t^{1+\nu} \bar{H}_t^{-\nu},$$

where $\tilde{\sigma}, \nu > 0$, and $\{\bar{C}_t, \bar{H}_t\}$ are bounded exogenous disturbance processes. (We use the notation ξ_t to refer to the complete vector of exogenous disturbances, including $\bar{C}_t$ and $\bar{H}_t$.)

We assume a common technology for the production of all goods, in which (industry-specific) labor is the only variable input,

$$y_t(i) = A_t f(h_t(i)) = A_t h_t(i)^{1/\phi},$$

where A_t is an exogenously varying technology factor, and $\phi > 1$. Inverting the production function to write the demand for each type of labor as a function of the quantities produced of the various differentiated goods, and using the identity

$$Y_t = C_t + G_t$$

to substitute for C_t, where G_t is exogenous government demand for the composite good, we can write the utility of the representative household as a function of the expected production plan $\{y_t(i)\}$.[4]

The producers in each industry fix the prices of their goods in monetary units for a random interval of time, as in the model of staggered pricing introduced by Calvo (1983). We let $0 \leq \alpha < 1$ be the fraction of prices that remain unchanged in any period. A supplier that changes its price in period t chooses its new price $p_t(i)$ to maximize

$$E_t \left\{ \sum_{T=t}^{\infty} \alpha^{T-t} Q_{t,T} \Pi(p_t(i), p_T^j, P_T; Y_T, \tau_T, \xi_T) \right\}, \qquad (1.3)$$

[4]The government is assumed to need to obtain an exogenously given quantity of the Dixit-Stiglitz aggregate each period, and to obtain this in a cost-minimizing fashion. Hence the government allocates its purchases across the suppliers of differentiated goods in the same proportion as do households, and the index of aggregate demand Y_t is the same function of the individual quantities $\{y_t(i)\}$ as C_t is of the individual quantities consumed $\{c_t(i)\}$, defined in (1.2).

where $Q_{t,T}$ is the stochastic discount factor by which financial markets discount random nominal income in period T to determine the nominal value of a claim to such income in period t, and α^{T-t} is the probability that a price chosen in period t will not have been revised by period T. In equilibrium, this discount factor is given by

$$Q_{t,T} = \beta^{T-t} \frac{\tilde{u}_c(C_T;\xi_T)}{\tilde{u}_c(C_t;\xi_t)} \frac{P_t}{P_T}. \tag{1.4}$$

The function

$$\begin{aligned} \Pi(p, p^j, P; Y, \tau, \xi) \equiv & \ (1-\tau) p Y (p/P)^{-\theta} \\ - & \ \mu_t^w \frac{\tilde{v}_h(f^{-1}(Y(p^I/P)^{-\theta}/A);\xi)}{\tilde{u}_c(Y-G;\xi)} P \cdot f^{-1}(Y(p/P)^{-\theta}/A) \end{aligned}$$

indicates the after-tax nominal profits of a supplier with price p, in an industry with common price p^j, when the aggregate price index is equal to P, aggregate demand is equal to Y, and sales revenues are taxed at rate τ. Profits are equal to after-tax sales revenues net of the wage bill. The real wage demanded for labor of type j is assumed to be given by an exogenous markup factor μ_t^w (allowed to vary over time, but assumed common to all labor markets) times the marginal rate of substitution between work of type j and consumption, and firms are assumed to be wage-takers. We allow for wage markup variations in order to include the possibility of a "pure cost-push shock" that affects equilibrium pricing behavior while implying no change in the efficient allocation of resources. Note that variation in the tax rate τ_t has a similar effect on this pricing problem (and hence on supply behavior); so in the case that the evolution of the tax rate is treated as an exogenous political constraint, variations in the tax rate are also examples of pure cost-push shocks.

We abstract here from any monetary frictions that would account for a demand for central-bank liabilities that earn a substandard rate of return; we nonetheless assume that the central bank can control the riskless short-term nominal interest rate i_t,[5] which is in turn related to other financial asset prices through the arbitrage relation

$$1 + i_t = [E_t Q_{t,t+1}]^{-1}. \tag{1.5}$$

We assume that the zero lower bound on nominal interest rates never binds under the optimal policies considered below, so that we need not introduce any additional

[5] For discussion of how this is possible even in a "cashless" economy of the kind assumed here, see Woodford (2003, chapter 2).

constraint on the possible paths of output and prices associated with a need for the chosen evolution of prices to be consistent with a non-negative nominal interest rate.

Our abstraction from monetary frictions, and hence from the existence of seignorage revenues, does not mean that monetary policy has no fiscal consequences, for interest-rate policy and the equilibrium inflation that results from it have implications for the real burden of government debt. In our baseline analysis, we assume that all public debt consists of riskless nominal one-period bonds.[6] The nominal value B_t of end-of-period public debt then evolves according to a law of motion

$$B_t = (1 + i_{t-1})B_{t-1} + P_t s_t, \tag{1.6}$$

where the real primary budget surplus is given by

$$s_t \equiv \tau_t Y_t - G_t - \zeta_t, \tag{1.7}$$

where ζ_t represents the real value of (lump-sum) government transfers. Rational-expectations equilibrium requires that the expected path of government surpluses must satisfy an intertemporal solvency condition

$$b_{t-1} \frac{P_{t-1}}{P_t} = E_t \sum_{T=t}^{\infty} R_{t,T} s_T \tag{1.8}$$

in each state of the world that may be realized at date t, where $R_{t,T} \equiv Q_{t,T} P_T / P_t$ is the stochastic discount factor for a real income stream.

We shall consider alternative assumptions about the degree of endogeneity of the various contributions to the government budget in (1.7). In the case corresponding to the conventional literature on optimal monetary stabilization policy, both G_t and τ_t are exogenous processes (among the real disturbances to which monetary policy may respond), but ζ_t can be adjusted endogenously to ensure intertemporal solvency in a way that creates no deadweight loss, so that the fiscal consequences of monetary policy are of no significance for welfare. In a more realistic case that we consider next, G_t and ζ_t are exogenous disturbances, and additional government revenue has a positive shadow value, but τ_t can be varied endogenously so as to minimize deadweight loss. In the most constrained case, where the concerns stressed by Sims (2005) arise, G_t, τ_t, and ζ_t are all exogenous processes determined by political constraints.

[6]The consequences of longer-maturity public debt are discussed in section 3.3 below.

1.2 An Associated Linear-Quadratic Policy Problem

We approximate the solution to our optimal policy problem by the solution to an associated linear-quadratic (LQ) problem, as in Benigno and Woodford (2003), where the derivation of the approximations is presented in detail. We show that we can define an LQ problem with the property that the solution to the LQ problem is a linear approximation to optimal policy in the exact model, for the case in which the exogenous disturbances are small enough.

First, we show that maximization of expected utility is (locally) equivalent to minimization of a discounted loss function of the form

$$E_{t_0}\sum_{t=t_0}^{\infty}\beta^{t-t_0}\left\{\frac{1}{2}q_y(\hat{Y}_t-\hat{Y}_t^*)^2+\frac{1}{2}q_\pi\pi_t^2\right\}, \tag{1.9}$$

where the target output level Y_t^* is a function of exogenous disturbances. If steady-state tax distortions are not too extreme, we show that $q_y, q_\pi > 0$, and the loss function is convex, as assumed in conventional accounts of the goals of monetary stabilization policy.

The constraints on possible equilibrium outcomes are given by log-linear approximations to the structural equations of the model described above. Here we omit derivations and proceed directly to the log-linear forms. First, there is an aggregate-supply relation between current inflation and real activity,

$$\pi_t = \kappa[\hat{Y}_t + \psi\hat{\tau}_t + c_\xi'\xi_t] + \beta E_t\pi_{t+1}, \tag{1.10}$$

where $\kappa, \psi > 0$. This is the familiar "New Keynesian Phillips curve," augmented to take note of the cost-push effects of variations in the sales tax. It is useful to write the constraint in terms of the welfare-relevant *output gap* $y_t \equiv \hat{Y}_t - \hat{Y}_t^*$, in which case (1.10) becomes

$$\pi_t = \kappa[y_t + \psi\hat{\tau}_t + u_t] + \beta E_t\pi_{t+1},$$

where u_t is a composite "cost-push" term (associated with exogenous disturbances other than variations in the tax rate[7]), or

$$\pi_t = \kappa[y_t + \psi(\hat{\tau}_t - \hat{\tau}_t^*)] + \beta E_t\pi_{t+1}, \tag{1.11}$$

[7]An obvious source of such disturbances would be variations in the wage markup μ_t^w, and when the steady state involves no distortions, this is the only source of variations in u_t. However, in the case of a distorted steady state, most other kinds of real disturbances also have cost-push effects, as shown in Benigno and Woodford (2003), as they do not move the flexible-price equilibrium level of

where $\hat{\tau}_t^*$ is a function of exogenous disturbances that indicates the tax change needed to offset the other "cost-push" terms.

There is also another constraint on the possible equilibrium paths of inflation, output and tax rates, and that is the condition for intertemporal government solvency (1.8).[8] A log-linear approximation to (1.8) takes the form

$$\hat{b}_{t-1} - \pi_t - \sigma^{-1} y_t = -f_t + (1-\beta) E_t \sum_{T=t}^{\infty} \beta^{T-t} [b_y y_T + b_\tau (\hat{\tau}_T - \hat{\tau}_T^*)] \qquad (1.12)$$

where f_t is a composite of the various exogenous disturbances that we refer to as "fiscal stress." Because we have written the constraint in terms of the output gap and the "tax gap" $\tau_t - \tau_t^*$ (indicating departures of the tax rate from the level consistent with complete stabilization of both inflation and the output gap), the term f_t (or, more precisely, the sum $\hat{b}_{t-1} + f_t$) measures the extent to which intertemporal solvency prevents complete achievement of the stabilization goals represented in (1.9).

Here we have substituted (1.4) for the stochastic discount factor (and replaced C_t by $Y_t - G_t$), in order to obtain a relation that involves only the initial public debt and the paths of inflation, output, taxes and the various exogenous variables. Note that we have taken account of the effects of interest-rate policy on debt dynamics (the key to the scenarios of Loyo (1999) and Blanchard (2005) under which tight money can be inflationary) through the presence of the stochastic discount factor in (1.8), which is linked to the interest rate controlled by the central bank through (1.5). Interest rates do not appear in (1.12) because we have already substituted for them using the connection between interest rates and the paths of output and inflation that must hold in equilibrium, but the effect of tight money on the burden of the public debt is nonetheless taken account of in this equation.

In writing (1.12) in the form given, we have treated ζ_t (real net transfers) as one of the exogenous disturbances that affects the fiscal stress term. In the case that net

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output to precisely the same extent (in percentage terms) as they move the efficient level of output. The latter sources of cost-push terms become more important the greater the magnitude of the steady-state distortions.

[8] This does not amount to requiring that fiscal policy be "Ricardian"; we do consider below the consequences of non-Ricardian fiscal policies of the kind assumed in the warnings of Sims (2005). Instead, (1.8) is a condition that must hold *in equilibrium* under any policy, and in considering what is the best equilibrium that can be achieved under certain constraints on possible policies, (1.8) constrains the possible outcomes that can be achieved.

transfers are endogenous, and can be varied to ensure solvency, we need to separate out the ζ_t term from the other (exogenous) determinants of f_t. However, in this case, the solvency constraint ceases to bind, given that the level of transfers affects neither the aggregate-supply tradeoff (1.11) nor the loss function (1.9), so that policymakers are free to vary ζ_t as necessary in order to satisfy (1.12). Thus we do not need to write the solvency constraint, except for the case in which ζ_t is exogenous.

2 Optimal Inflation Targeting: The Conventional Analysis

We begin by using the framework sketched in the previous section to recapitulate well-known arguments for a form of "flexible inflation targeting" as a way of implementing an optimal state-contingent monetary policy, highlighting the role of (often tacit) assumptions about fiscal policy in deriving these familiar results.[9]

The conventional analysis of optimal monetary stabilization policy in a "New Keynesian" model corresponds to the case of the above model in which the processes $\{G_t, \tau_t\}$ are both exogenously given as political constraints on what policy can achieve, while the level of net lump-sum transfers ζ_t is instead an endogenous policy variable (along with the short-term nominal interest rate). When lump-sum transfers can be chosen to facilitate stabilization policy, the intertemporal solvency constraint ceases to bind, and can be omitted from our description of the policy problem, and we can similarly omit any reference to the path of the public debt. Moreover, when the level of distorting taxes is given exogenously, we can treat the $\hat{\tau}_t$ term in (1.10) in the same way as the other cost-push terms.

The problem of optimal stabilization policy is then simply to find paths $\{\pi_t, y_t\}$ to minimize (1.9) subject to the single constraint

$$\pi_t = \kappa[y_t + u_t] + \beta E_t \pi_{t+1}, \tag{2.1}$$

where the definition of u_t is now modified to include the cost-push effects of variations in τ_t (if these are present). This is the optimal policy problem treated, for example, in

[9] See, *e.g.*, Clarida *et al.* (1999), Svensson (2003), Woodford (2003, chaps. 7-8; 2004), or Svensson and Woodford (2005) for more detailed presentations of the arguments summarized here.

Clarida *et al.* (1999). Here we emphasize the respects in which this conception of the goals of monetary stabilization policy provides an argument for inflation targeting.

A first, simple conclusion about optimal policy under these assumptions is that, in the absence of cost-push disturbances, optimal policy would involve adjusting interest rates as necessary in order to maintain *zero inflation* at all times. This is easily seen from the fact that if $u_t = 0$ at all times, equation (2.1) is consistent with maintaining both a zero inflation rate and a zero output gap at all times, and such an outcome obviously minimizes the loss function (1.9).

This provides one argument for inflation targeting: if cost-push shocks are unimportant (because distortions due to market power and/or taxes are both small on average and fairly stable over time), then a low, stable inflation rate is optimal, regardless of the degree of variability in real activity that this may entail (owing to the effects of disturbances to preferences and technology on Y_t^*). But it also implies something of more general validity: even when random cost-push shocks of substantial magnitude *do* occur, optimal policy should involve zero inflation *on average.* (This follows from the previous result using the certainty-equivalence property of linear-quadratic optimization problems.[10]) Thus the optimal long-run inflation target is quite low (zero, in our simple model), regardless of the degree of distortions in the economy, and thus of the degree to which the optimal level of output may exceed the level associated with stable prices. And given that the departures from this constant long-run average inflation rate due to cost-push shocks should be transitory, expected inflation "in the medium term" should always be near zero. Thus our result justifies a policy that seeks to maintain low and stable medium-term inflation expectations, as at least one criterion that an optimal policy should satisfy.

The conception of optimal stabilization policy just proposed also provides an important reason for a central bank to commit itself to an explicit target for inflation, rather than for other variables (such as real activity), even in the case where cost-push shocks are expected to be non-trivial. In the optimal control of a forward-looking system — the kind of problem just posed above — there are generally advantages from advance commitment of policy, for the sake of influencing expectations at earlier dates in a way that improves the available stabilization outcomes at those dates. But what aspect of expectations about the future matter? When the only constraint on

[10]See Svensson and Woodford (2003) for discussion of certainty equivalence in the context of policy problems with forward-looking constraints, like the one considered here.

what policy can achieve is the aggregate-supply relation (2.1), the only aspect of future expectations that affect the inflation and output gap that can be achieved in some period t are the expectations regarding future inflation, $E_t\pi_{t+1}$. Hence this is the type of commitment that is directly relevant: committing to achieve a particular *rate of inflation* in the future, that might be different from what would otherwise be chosen later to best achieve one's stabilization goals at that time. Given that the role of a policy commitment should be to anchor the public's inflation expectations, a commitment regarding future inflation, and communication by the central bank regarding the outlook for inflation, are straightforward ways of trying to achieve the benefits associated with an optimal policy commitment.

Beyond these general considerations, one can easily characterize the optimal state-contingent evolution of prices and quantities under a particular assumption about the character of the disturbances affecting the economy (though this aspect of our conclusions will obviously be much more dependent upon the precise details of our assumed model of the transmission mechanism of monetary policy). Associated with the policy problem stated above are the first-order conditions

$$q_\pi \pi_t = \kappa^{-1}(\varphi_t - \varphi_{t-1}), \tag{2.2}$$

$$q_y y_t = \varphi_t, \tag{2.3}$$

each of which must hold for each $t \geq 0$. Here φ_t is the Lagrange multiplier associated with the aggregate-supply constraint (2.1). We can solve conditions (2.2)–(2.3), together with the aggregate-supply relation (2.1), for the optimal evolution of $\{\pi_t, y_t\}$ given the disturbances $\{u_t\}$.

The optimal state-contingent responses can be *implemented* through commitment to a constant target for the *output-gap-adjusted* price level

$$\tilde{p}_t \equiv p_t + \frac{q_y}{\kappa q_\pi} y_t, \tag{2.4}$$

where p_t denotes $\log P_t$, as discussed in Woodford (2003, chap. 7). A *targeting rule* of this form determines the optimal tradeoff between price increase and output decline that should be selected when the shock occurs; the stance of policy should be neither so tight as to cause $\tilde{p}_t$ to decline (as would be required in order for there to be no increase in prices) nor so loose as to allow $\tilde{p}_t$ to increase (as would be required in order for there to be no reduction in output relative to target output). At the same,

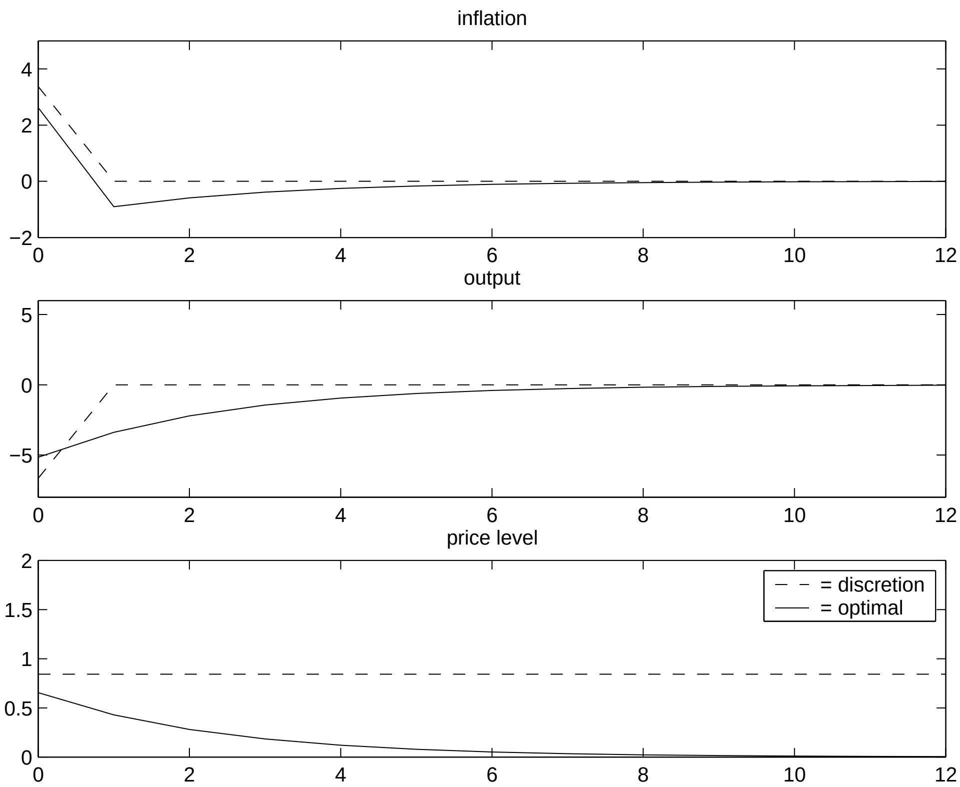

Figure 1: Impulse responses to a transitory cost-push shock, under discretionary policy and under an optimal commitment.

commitment to adhere to such a rule in the future as well automatically implies invariance of the expected long-run price level and output gap, and determines the optimal rate of return of both variables to those long-run levels. One should neither try to return the output gap to zero too quickly (this would allow prices to remain high and so involve an increase in the gap-adjusted price level), nor too slowly (in which case the gap-adjusted price level would fall once the cost-push disturbance has dissipated). As an example, Figure 1 shows the optimal impulse responses of inflation and the output gap to a purely transitory positive cost-push shock (*i.e.*, the solution to the first-order conditions listed above in the case of such a disturbance).[11] [12] One

[11]This calculation is further explained in Woodford (2003, chap. 7), from which the figure is taken (see Figure 7.3 of the book). The parameter values assumed are $\beta = 0.99$, $\kappa = 0.024$, and $q_y/q_\pi = 0.048$.

[12]The figure also shows, for purposes of comparison, the equilibrium responses that would occur

notes that the dynamic paths of the log price level and of the output gap are perfect mirror images of one another, up to scale, so that $\tilde{p}_t$ is not allowed to vary.

This is an example of a *robustly optimal* policy rule in the sense of Giannoni and Woodford (2002): commitment to the *same* target criterion is optimal, regardless of the statistical properties of the disturbance process. (The optimal dynamic responses shown in Figure 1 will be different in the case of a shock that is not completely transitory and or not wholly unexpected when it occurs; but it is always the case that the optimal responses of p_t and y_t mirror one another in the way shown in the figure.) This is because the first-order conditions (2.2)–(2.3) can be directly used to show that $\tilde{p}_t$ must not change over time under an optimal policy, without making any assumptions about the nature of the disturbance.

Such a policy prescription can be viewed as a form of "flexible inflation targeting," since the requirement that $\Delta\tilde{p}_t = 0$ can equivalently be written as

$$\pi_t + \frac{q_y}{\kappa q_\pi}\Delta y_t = 0.$$

In this form, the rule states that the acceptable rate of inflation at any point in time should vary depending on the rate of change of the output gap. Svensson and Woodford (2005) discuss a more realistic version of this prescription, in which delays in the effects of monetary policy on spending and prices are taken account of. Here, instead, we are interested in the ways in which this familiar analysis must be complicated under alternative assumptions about fiscal policy.

3 Optimal Policy when Only Distorting Taxes Are Available: The Case of Optimal Tax Smoothing

It is more realistic, of course, to assume that lump-sum taxes are not available to offset the fiscal consequences of monetary policy decisions. In the case that we assume the process $\{\zeta_t\}$ to be exogenously given, the intertemporal solvency condition represents an additional binding constraint on the set of possible equilibrium paths for inflation

under discretionary optimization. In this case, the gap-adjusted price level does not change in the period of the shock, but it is expected that it will be allowed to rise subsequently, and this expectation results in a less favorable inflation-output tradeoff for the central bank in the period of the shock.

and output. In Benigno and Woodford (2003), we consider optimal monetary policy in such an environment, under the assumption that the path of the distorting tax rate $\{\tau_t\}$ is chosen *optimally* in response to the various types of real disturbances considered in the model. Here we recapitulate the main conclusions of that analysis, before turning to cases in which fiscal policy is assumed to be less flexible and/or not optimally determined.

In this case, we can view monetary and fiscal policy decisions as being jointly determined in a coordinated fashion so as to solve a single social welfare problem. The planning problem is to find state-contingent paths $\{\pi_t, y_t, \hat{\tau}_t\}$ to minimize (1.9) subject to the *two* constraints (1.11) and (1.12). An especially simple case of this problem is the limiting case in which prices are perfectly flexible. This case is worth mentioning since it is easy to see why the absence of lump-sum taxes *can* make it optimal for the inflation rate to be highly responsive to fiscal developments, contrary to what inflation targeting is generally assumed to imply; and analyses of this kind have sometimes been argued to be relevant to the choice of monetary institutions in Latin America (Sims, 2002).

3.1 Optimal Policy if Prices are Flexible

In the flexible-price limit of the above model, the coefficient q_π in (1.9) is equal to zero, and κ^{-1} in (1.11) is also zero (*i.e.*, the aggregate-supply relation is completely vertical). The policy problem reduces to the minimization of

$$\frac{1}{2} q_y E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} y_t^2 \tag{3.1}$$

subject to the constraints

$$y_t + \psi(\hat{\tau}_t - \hat{\tau}_t^*) = 0 \tag{3.2}$$

and (1.12). Using (3.2) to substitute for y_t in (3.1) allows us to equivalently write the stabilization objective as

$$E_{t_0} \sum_{t=t_0}^{\infty} \beta^{t-t_0} (\hat{\tau}_t - \hat{\tau}_t^*)^2,$$

in which case the objective of policy can be thought of as *tax smoothing*, as in the classic analysis of Barro (1979).[13]

The solution will obviously involve $y_t = 0$ at all times, since it is feasible to achieve this, if the monetary and fiscal authorities cooperate to do so. The fiscal authority must choose $\hat{\tau}_t = \hat{\tau}_t^*$ at all times in order to ensure this, while the monetary authority must vary the inflation rate π_t as necessary to ensure government solvency. It is easily seen that (1.12) requires that in such an equilibrium,

$$\pi_t = \hat{b}_{t-1} + f_t.$$

Thus unexpected changes in the fiscal stress term must be accommodated entirely by surprise variations in the rate of inflation, as in the analysis of Chari and Kehoe (1999). The tax rate should fluctuate only to extent that there are fluctuations in $\hat{\tau}_t^*$; *i.e.*, only to the extent that variations in the tax rate are useful as *supply-side* policy, to offset inefficient supply disturbances.[14]

This conclusion implies that an optimal policy will involve highly volatile inflation, and extreme sensitivity of inflation to fiscal shocks in particular. This is the basis of Sims' (2002) critique of dollarization as a policy prescription for Mexico; at least a strict form of inflation targeting would presumably be rejected on the same grounds. But the analysis just sketched neglects the welfare costs of volatile inflation, which are stressed in the literature on inflation targeting. Here we wish to consider how important the Chari-Kehoe argument should be expected to be, in the presence of a realistic degree of price stickiness.

3.2 Optimal Policy if Prices are Sticky

In the more general case of our model (with some degree of stickiness of prices), the first-order conditions for the optimal policy problem stated above are

$$q_\pi \pi_t = \kappa^{-1}(\varphi_{1t} - \varphi_{1,t-1}) - (\varphi_{2t} - \varphi_{2,t-1}) \tag{3.3}$$

$$q_y y_t = \varphi_{1t} - [(1-\beta)b_y + \sigma^{-1}]\varphi_{2t} + \sigma^{-1}\varphi_{2,t-1} \tag{3.4}$$

[13] Thus our stabilization objective (1.9) has not omitted the concerns of the literature on optimal tax smoothing; the welfare losses associated with a failure to optimally time the collection of taxes are already implicit in the output-gap stabilization objective.

[14] As shown in Benigno and Woodford (2003), there are a wide variety of types of inefficient supply disturbances that may require such an offset, in the case that the steady state is sufficiently distorted as a result of either market power or a high level of public debt.

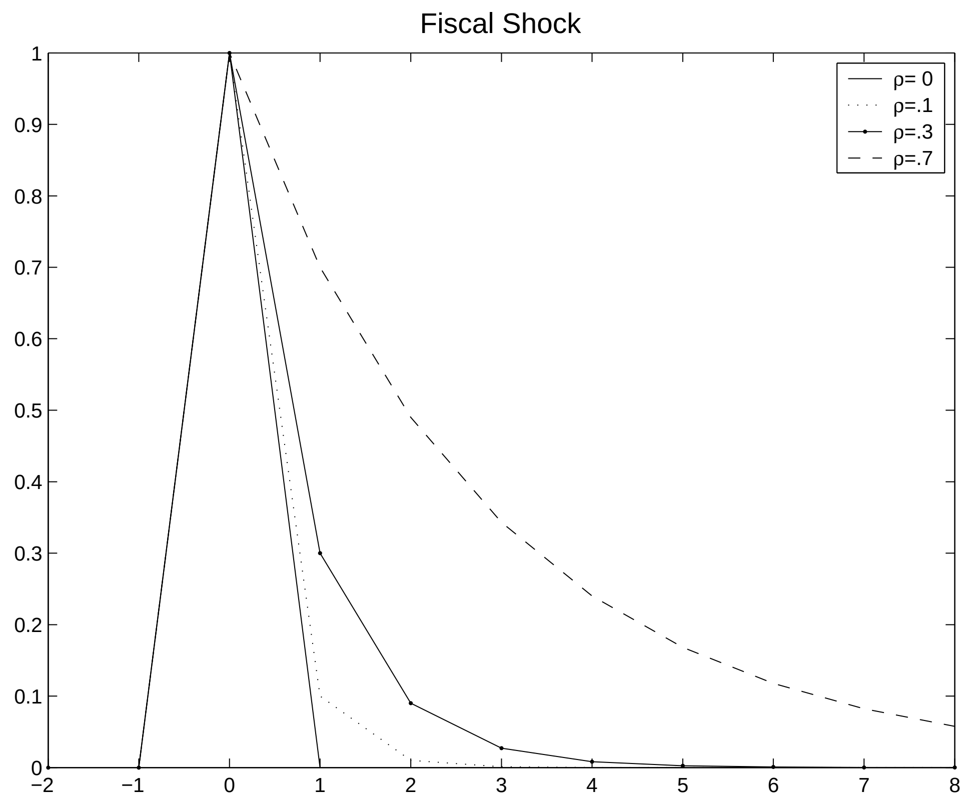

Figure 2: Alternative fiscal shocks.

$$\varphi_{2t} = E_t \varphi_{2,t+1} \tag{3.5}$$

$$\psi \varphi_{1t} = (1-\beta) b_\tau \varphi_{2t} \tag{3.6}$$

where now φ_{1t} is the Lagrange multiplier associated with the aggregate supply relation and φ_{2t} is the multiplier associated with the intertemporal solvency condition. Conditions (3.3)–(3.6) together with the two structural equations (1.11) and (1.12) are to be solved for the paths of the endogenous variables $\{\pi_t, y_t, \hat{\tau}_t, \hat{b}_t, \varphi_{1t}, \varphi_{2t}\}$, given an exogenous process for $\{f_t\}$.

The type of response to shocks implied by these equations can be illustrated using a numerical example. As in Benigno and Woodford (2003), we adopt the parameter values $\beta = 0.99, \omega = 0.473, \sigma^{-1} = 0.157$, $\kappa = 0.0236$, $\theta = 10, \bar{\tau} = 0.2, \bar{b}/\bar{Y} = 2.4$, and

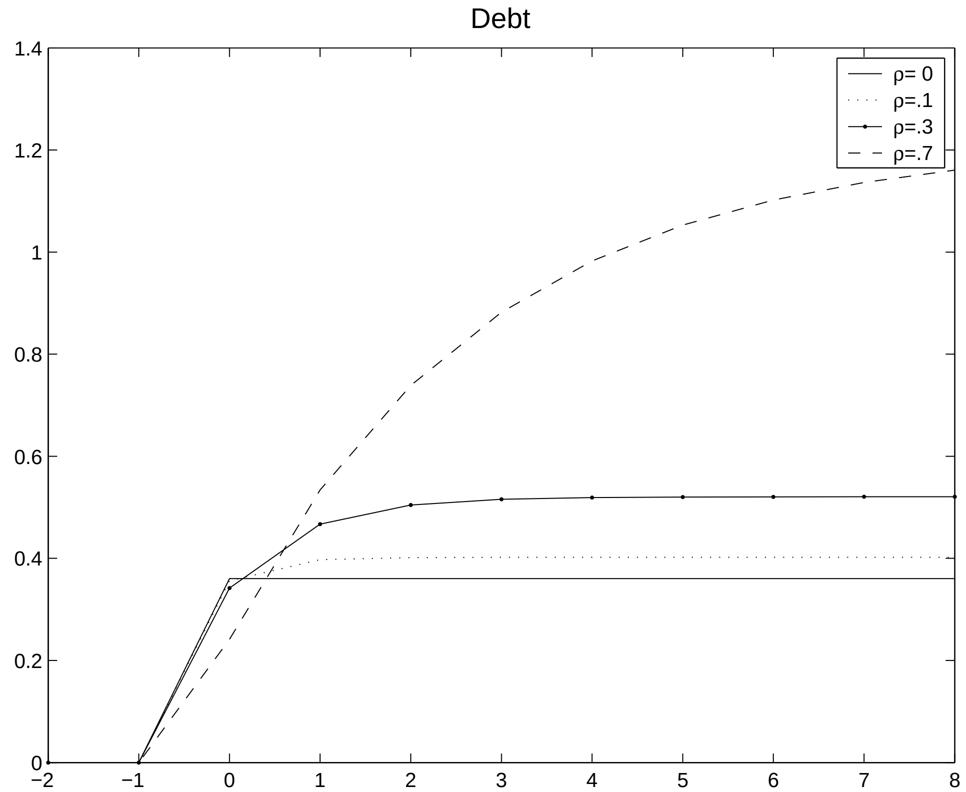

Figure 3: Impulse response of the public debt to a pure fiscal shock, for alternative degrees of persistence.

$\Phi = 1/3$.[15] As in that paper, we consider for purposes of illustration the effects of an exogenous increase in transfer programs $\hat{\zeta}_t$ equal to one percent of steady-state GDP. Here, however, we consider the consequences of alternative possible degrees of persistence of such a disturbance; we assume that the value of $\hat{\zeta}_t$ following the shock is expected to decay as ρ^t, where the coefficient of serial correlation ρ is allowed to take values between zero (the case shown in the earlier paper) and 0.7.

[15] Thus we assume a calibration in which steady-state tax revenues are 20 percent of GDP and the steady-state public debt is 60 percent of annual GDP [which corresponds to 2.4 times quarterly GDP]. Steady-state distortions are such that the social marginal cost of additional production would be 1/3 less than the price charged for goods; this requires that we assume a steady-state wage markup of 8 percent. The degree of price stickiness is calibrated on the basis of the estimates of Rotemberg and Woodford (1997) for the U.S., which correspond to an average time between price changes of 29 weeks.

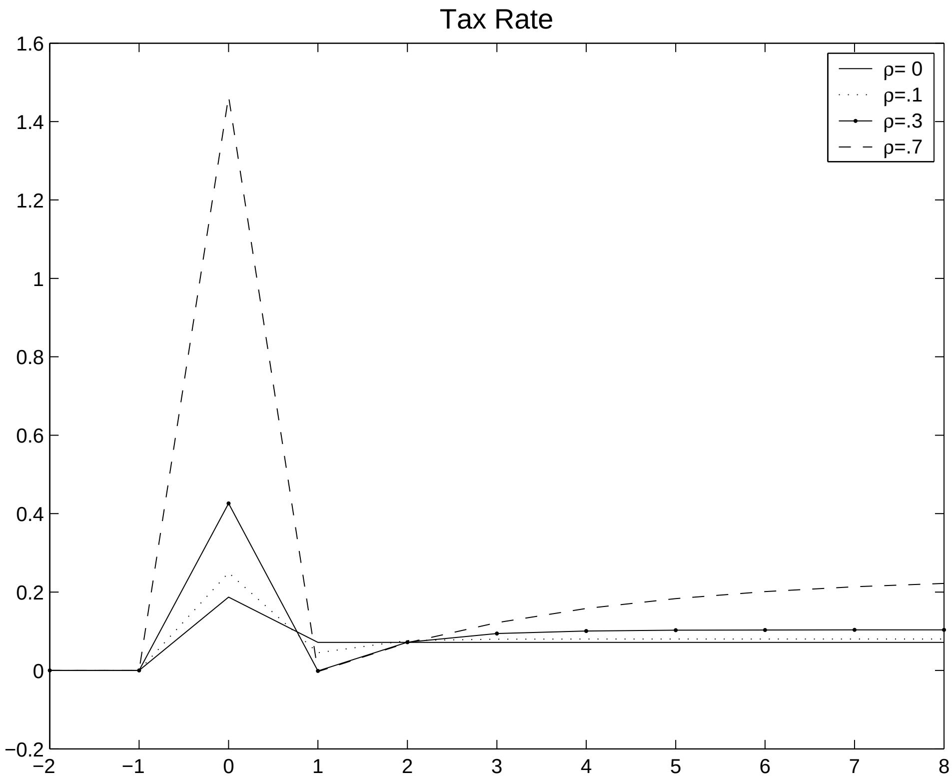

Figure 4: Impulse response of the tax rate to a pure fiscal shock, for alternative degrees of persistence.

Figure 2 shows the impulse response of the shock $\hat{\zeta}_t$ for the different values of ρ considered. Figure 3 then shows the impulse response of the public debt $\hat{b}_t$ in response to a pure fiscal shock of this kind under the optimal policy, for each of the alternative values of ρ. Figure 4 shows the corresponding responses of the tax rate $\hat{\tau}_t$ under the optimal policy, and Figure 5 the associated responses of the inflation rate. Contrary to the optimal policy in the case of flexible prices (discussed further in Benigno and Woodford, 2003), it is optimal to respond to a "pure fiscal shock" of this kind by permanently increasing the level of real public debt, and by planning on a corresponding permanent increase in the tax rate. (The increase in the level of the real public debt under the optimal policy is more gradual the greater the degree of persistence of the fiscal shock, whereas it was immediate in the case of the purely transitory shock considered in our previous paper.) Optimal policy does involve some unanticipated inflation at the time of the shock, as in the Chari-Kehoe analysis, but

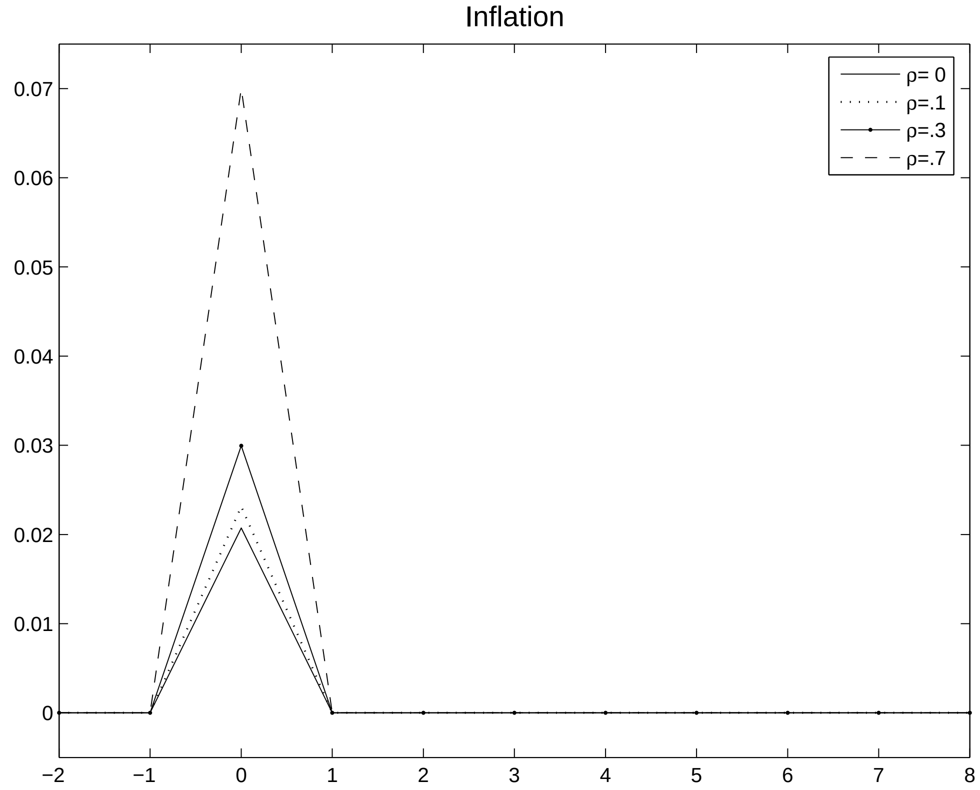

Figure 5: Impulse response of the inflation rate to a pure fiscal shock, for alternative degrees of persistence.

it is not nearly large enough to offset the fiscal stress completely, which is why future taxes are also increased.

In fact, as shown in Figure 5, the inflationary impact of a fiscal shock under the optimal policy regime is quite small. In the case of a purely transitory (one-quarter) increase in the size of transfer programs by an amount equal to one percent of GDP, optimal policy allows an increase in the inflation rate that quarter of only *two basis points* (at an annualized rate,[16] and the increase in inflation is limited to the quarter of the shock. This compares with an increase in the inflation rate of nearly two percentage points under the optimal policy in the case of flexible prices. Nor is the conclusion that the optimal inflation response is small dependent upon an extreme calibration of the degree of price stickiness. Benigno and Woodford (2003) shows that the optimal response (to a purely transitory fiscal shock) is similarly small even if

[16]Thus the log price level is allowed to increase that quarter by only half a basis point.

prices are assumed to be much less sticky than under the calibration used here; there is a dramatic difference between optimal policy in the case of *full* flexibility of prices and what is optimal if prices are even slightly sticky (*i.e.,* the short-run aggregate-supply tradeoff is not *completely* vertical). The optimal inflation response is larger if the shock is more persistent, since in this case the cumulative cost of the increased transfers, and hence the total increase in fiscal stress, is several times as large. But even in the case that $\rho = 0.7$, the optimal increase in the inflation rate is only about 7 basis points. And the effect on inflation is *purely transitory* under optimal policy, regardless of the degree of persistence of the fiscal shock itself.

This last conclusion — that variations in inflation should be purely transitory under the optimal policy, so that there are never any variations at all in the *expected* rate of inflation — is quite robust to the type of shock considered. The conclusion follows directly from the first-order conditions that characterize optimal policy. Condition (3.3) implies that forecastable variations in the inflation rate should be allowed only to the extent that there are forecastable variations in one or the other of the Lagrange multipliers. Condition (3.5) implies that there are no forecastable variations in the multiplier associated with the solvency constraint, while (3.6) implies that the two multipliers should covary perfectly with one another, so that there are no forecastable variations in the multiplier associated with the aggregate-supply constraint either, under an optimal policy.

So it is true that if only distorting sources of government revenue exist, the fiscal consequences of monetary policy matter; and this creates additional reasons for departures from strict price stability to be optimal. It is now optimal for the inflation rate to vary, at least to some extent, in response to disturbances (such as a change in the size of government transfer programs) that are irrelevant in the classic analysis reviewed in the previous section. But optimal policy continues to possess important features of an inflation targeting regime. The rate of inflation that is forecastable for the future should never vary, regardless of the kind of disturbances hitting the economy; and the unforecastable variations in inflation that should be allowed are quite small.

It is true that it is no longer optimal to target a constant value for the output-gap-adjusted price level $\tilde{p}_t$; in fact, the optimal policy is now one that will involve some degree of "base drift" in the price level, since the transitory inflation shown in Figure 5 permanently shifts the price level. Nonetheless, it is possible to characterize optimal monetary policy by commitment to a target criterion that is only a slight generalization of the one presented above for the case where lump-sum taxes exist. We return to this topic in section 6 below.

3.3 Consequences of Additional Fiscal Instruments

The analysis of Benigno and Woodford (2003) assumes that a small and quite specific set of policy instruments are available to the fiscal authority: the only source of government revenue is a proportional sales tax, and the only kind of government debt that may be issued is a very short-term (one-period) riskless nominal bond. Here we briefly discuss the consequences of allowing for additional instruments, and hence a broader range of possible fiscal policies.

Not surprisingly, additional fiscal instruments, if used skilfully enough, can allow a better equilibrium to be achieved; and this can make it simpler to characterize optimal monetary policy, as the need for a limited set of instruments to simultaneously serve multiple stabilization objectives ceases to be a problem. Suppose, for example, that it is possible to independently vary the level of several different types of distorting taxes. With two distinct tax rates, the cost-push term $\psi\hat{\tau}_t$ in (2.1) becomes instead $\psi_1\hat{\tau}_{1t} + \psi_2\hat{\tau}_{2t}$, while the term $b_\tau\hat{\tau}_t$ in (1.12) becomes instead $b_1\hat{\tau}_{1t} + b_2\hat{\tau}_{2t}$. In general, not only will there be different elasticities in the case of different taxes, but the *ratios* of the elasticities will not be the same in the two equations; the fact that a given percentage increase in one tax results in a 20 percent larger increase in revenues in the case of one tax than another does not imply that it also results in a 20 percent larger "cost-push" effect. Thus the existence of multiple taxes that can be independently varied (and are not at some boundary value under an optimal policy) will generally imply that the fiscal authority can *independently* shift the aggregate-supply relation and affect the government's budget.

If this is possible, then a lump-sum tax is essentially possible, as some combination of tax increases and decreases will be able to increase tax revenues without any net effect on the aggregate-supply relation.[17] But this does not return us to the classic situation analyzed in section 2. In fact, matters are even simpler, for tax policy can

[17] Here we assume that the various taxes in question affect all sectors of the economy identically, as in the case that both a sales tax and a wage income tax exist. Under this assumption, taxes create no distortions other than the effect indicated by the cost-push term in the aggregate-supply relation.

in this case *also* be used to offset the cost-push effects of other disturbances, without any consequences for government solvency. So constraint (1.12) ceases to bind, as in section 2, but tax policy can be used to shift the aggregate-supply relation, as in sections 3.1 and 3.2. Optimal policy then involves using taxes to offset the cost-push term u_t entirely, and then using monetary policy to completely stabilize both inflation and the output gap. (Taxes are also used to ensure that this equilibrium is consistent with intertemporal government solvency.) In such a case, the optimal monetary policy will be a *strict inflation target*, that maintains $\pi_t = 0$ at all times, regardless of the shocks to which the economy may be subject.[18]

This indicates that when tax policy can be varied in any of a range of directions, and the fiscal authority can be expected to exercise its power skilfully, the case for inflation targeting is quite strong indeed. But it is not obvious that this is the case of greatest practical interest. For instance, if the tax rates are each required to be non-negative, then it may be optimal to raise all revenue using only one tax, the one with the lowest ratio of ψ_j to b_j (hence the least distortion created per dollar of revenue raised); in such case, the optimal policy problem would end up being similar to the one treated above, where there is assumed to be only a single type of distorting tax.

Allowing for the possibility of issuing other forms of government debt would also increase the flexibility of fiscal policy, and reduce the constraints on what can be achieved by monetary policy. For example, if it were possible to issue arbitrary kinds of state-contingent debt, then in principle it would be possible to arrange for $\hat{b}_{t-1}$ to vary with the state that is realized at date t in such a way that $\hat{b}_{t-1} + f_t$ never varies, regardless of the exogenous disturbances. In such case, complete stabilization of both inflation and the output gap would again be possible; hence the optimal monetary policy would be a strict inflation target of zero. However, the supposition that state-contingent payoffs on government debt can be arranged in such a sophisticated way is hardly realistic.

One way in which it surely is possible for countries to vary the kind of debt that they issue is with respect to maturity. If government debt does not all mature in one period, then $\hat{b}_{t-1}$ is no longer a predetermined state variable; instead, it will

[18] Our ability to achieve the first-best outcome with a sufficient number of taxes is reminiscent of the conclusion of Correia *et al.* (2003) in the context of a model with a different kind of price stickiness.

depend on the market valuation of bonds in period t, which will generally depend on the shocks that occur at that date. Since the prices of bonds of different maturities will be sensitive to shocks occurring at date t in different ways, different maturity structures of the public debt will make $\hat{b}_{t-1}$ state-contingent in different ways. With a sufficient number of maturities available, it may well be possible once again to bring about the kind of state-contingency that makes $\hat{b}_{t-1} + f_t$ independent of shocks, so that there is no need for state-contingent debt, as proposed by Angeletos (2001). In this case, it would again be possible to fully stabilize both inflation and the output gap, and so once again a strict inflation target would be the optimal monetary policy.

It may be worth developing these points in more detail. Our analysis above can easily be extended to allow for the existence of longer-maturity nominal government debt. In the most general case, the intertemporal budget constraint (1.8) takes the form

$$E_t \left\{ \sum_{T=t}^{\infty} R_{t,T} s_T \right\} = E_t \left\{ \sum_{T=t}^{\infty} R_{t,T} b_{t-1,T} \frac{P_{t-1}}{P_T} \right\},$$

where for any $T \geq t$, $b_{t-1,T}$ denotes the real value at time $t-1$ of the debt that matures at time T. A log-linear approximation can be computed as before, yielding

$$\hat{b}_{t-1} - E_t \sum_{T=t}^{\infty} d_{T-t+1} \left[\sigma^{-1} y_T + \sum_{s=t}^{T} \pi_s \right] = -f_t + (1-\beta) E_t \sum_{T=t}^{\infty} \beta^{T-t} [b_y y_T + b_\tau (\hat{\tau}_T - \hat{\tau}_T^*)]. \tag{3.7}$$

Here we have defined

$$\hat{b}_{t-1} = \sum_{T=t}^{\infty} \beta^{T-t} \frac{(b_{t-1,T} - \bar{b}_{T+1-t})}{\bar{b}},$$

where $\bar{b}_i$ is the steady-state real value of i-period debt, and $\bar{b}$ is the steady-state real value of all outstanding government liabilities, given by

$$\bar{b} = \sum_{i=1}^{\infty} \beta^{i-1} \bar{b}_i.$$

The weights d_i are defined as $d_i = \beta^{i-1} \bar{b}_i / \bar{b}$ for each $i \geq 1$. Finally, the composite "fiscal stress" term f_t is now defined by

$$f_t = E_t \sum_{T=t}^{\infty} d_{T-t+1} \left[\sigma^{-1} (g_T - \hat{Y}_T^*) \right] - (1-\beta) E_t \sum_{T=t}^{\infty} \beta^{T-t} [b_y \hat{Y}_T^* + b_\tau \hat{\tau}_T^* + b'_\xi \xi_T],$$

which can be written in a more compact way as

$$f_t = E_t \sum_{T=t}^{\infty} d_{T-t+1} h'_\xi \xi_T + (1-\beta) E_t \sum_{T=t}^{\infty} \beta^{T-t} f'_\xi \xi_T, \tag{3.8}$$

again using the notation defined in Benigno and Woodford (2003).

The planning problem is to find state-contingent paths $\{\pi_t,\ y_t,\ \hat{\tau}_t\}$ to minimize (1.9) subject to constraints (1.11) and (3.7). As before the composite disturbance f_t completely summarizes the information at date t about the exogenous disturbances that interfere with complete stabilization of inflation and of the output gap. However, unlike what we found above for the case of only one-period debt, it can now be possible to completely stabilize output and inflation to their optimal level even when prices are sticky by appropriately choosing the steady-state structure of maturity. This is because the stochastic properties of the "fiscal stress" term now depend on the maturity structure; and with an appropriate choice of the maturity structure, one can even ensure that f_t is identically equal to zero at all times, in which case complete achievement of both stabilization objectives will be possible.

Let government debt have a maximum maturity of N periods and let J be the number of stochastic disturbances of the model. Let us suppose furthermore (purely for illustrative purposes, for our argument could easily be generalized) that the disturbances are all AR(1) processes,

$$\xi_t^j = \rho_j \xi_{t-1}^j + \varepsilon_t^j$$

where ε_t^j is a white-noise process and $|\rho_j| < 1$ for each disturbance j. In this case equation (3.8) takes the form

$$f_t = \sum_{i=1}^{N} d_i \sum_{j=1}^{J} \rho_j^i h_{\xi_j} \xi_t^j + (1-\beta) \sum_{j=1}^{J} (1-\rho_j \beta)^{-1} f_{\xi_j} \xi_t^j,$$

where h_{ξ_j} and f_{ξ_j} are the jth components of the vectors h_ξ and f_ξ, respectively.

It now follows (generically) that for f_t to be zero at all times, it is necessary and sufficient that

$$\sum_{i=1}^{N} {\rho_j}^i d_i = z_j \tag{3.9}$$

where z_j is defined by

$$z_j = (1-\beta)(1-\rho_j\beta)^{-1} h_{\xi_j}^{-1} f_{\xi_j}$$

for each j. Recalling that

$$\sum_{i=1}^{N} d_i = 1, \tag{3.10}$$

then equation (3.11) together

Then the set of J equations (3.9) together with the identity

$$\sum_{i=1}^{N} d_i = 1 \tag{3.11}$$

forms a set of $J+1$ equations in the N unknowns $\{d_i\}$. We can write this system of linear equations using matrix notation. To this end, we define the matrix

$$A \equiv \begin{bmatrix} 1 & \rho_1 & \dots & \rho_1{}^{N-1} \\ 1 & \rho_2 & \dots & \rho_2{}^{N-1} \\ \vdots & \vdots & \vdots & \vdots \\ 1 & \rho_J & \dots & \rho_J{}^{N-1} \\ 1 & 1 & \dots & 1 \end{bmatrix},$$

and let z be the vector whose first J elements are the z_j, and whose final element is 1. We can then write the system of linear equations in the compact form

$$Ad = z, \tag{3.12}$$

where d is the vector of coefficients d_i. Standard results ensure that there is a solution of (3.12) as long as A is of full rank. In this case, there is at least one vector d — i.e., at least one steady-state maturity structure — such that $f_t = 0$, so that complete stabilization of both inflation and the output gap can be achieved.

In particular, if $N = J + 1$, there is exactly one solution for any given z, when A is of full rank. For example, in the case of a single stochastic disturbance ($J = 1$), the matrix A is always of full rank, and it is possible to achieve the first-best outcome just by issuing nominal debt with one and two-period maturities. The optimal maturity structure in this case depends on the persistence of the shock, as well as on its contribution to movements in the fiscal stress measure f_t. If $J > 1$, A is of full rank if and only if $\rho_i \neq \rho_j$ for each i and j. (Otherwise there is in general no solution.)

Angeletos (2001) has shown in a flexible-price model that to complete the markets it is necessary and sufficient to issue nominal debt which has at least $N-$period maturity, where N is the number of states of nature in the model. Here we establish that in a log-linear model, as Angeletos conjectured on the basis of his numerical results, what matters is not the number of distinct states of nature but only the number of stochastic disturbances. Thus as long as debt can be issued in moderately long maturities, it will quite generally be possible, at least in principle, to choose a maturity structure that achieves the first-best outcome. In any such case, the optimal monetary policy will simply aim at complete price stability, while the distorting tax rate will be used to offset cost-push disturbances, so that zero inflation is compatible with a zero output gap.

However, as noted by Buera and Nicolini (2004) in a related context, the kind of maturity structure required for such an outcome may be quite implausible, involving very large long and short positions in different maturities. They also show that the optimal maturity structure may be extremely sensitive to small changes in model parameters, such as small changes in the serial correlation of disturbance processes. (This can be seen from our analysis above, since a small change in these parameters can cause the rank condition to fail.) Thus once again, while in principle the opportunity to increase the flexibility of fiscal policy in this way can greatly facilitate monetary stabilization policy, the practical relevance of this case is open to question. We shall accordingly restrict the remainder of our analysis in this paper to the case of a single maturity of government debt, specifically, one very short-term (single-period) debt. In fact, most countries with serious problems with fiscal imbalances are observed to issue almost exclusively short-maturity debt; so our assumption seems likely to represent the case of greatest relevance for the countries for which the concerns addressed in this paper are most likely to be relevant. We also note that this emphasis is consistent with our desire to consider the cases in which possible constraints on fiscal policy are most likely to create problems for inflation targeting. The presence of a larger number of fiscal instruments, or fewer constraints on the way in which they are used, will generally strengthen the case for inflation targeting; but our interest is in the extent to which a form of inflation targeting continues to be desirable even when fiscal policy is much less helpful.

4 Optimal Monetary Policy when Fiscal Policy is Exogenous

We next consider a still more constrained case, in which $\{G_t, \zeta_t, \tau_t\}$ are *all* assumed to be exogenous processes, determined by political factors that the central bank cannot influence. This is the type of fiscal policy assumed by Loyo (1999) in the analysis to which Sims (2005) refers in his critique of inflation targeting; in a flexible-price model of the kind assumed by Loyo, it implies a purely exogenous evolution of the real primary government budget surplus $\{s_t\}$. In such a case, the central bank must beware that a tight-money policy does not cause explosive growth of the public debt, for it is assumed that neither taxes nor government spending will be adjusted to prevent such dynamics.

In this case, the intertemporal solvency condition (1.12) constrains the possible paths for inflation and output that can be achieved by *any* monetary policy, and there are no endogenous fiscal instruments with which to adjust this constraint. At the same time, the possible paths for inflation and output are constrained by the aggregate-supply tradeoff (1.11), and — contrary to the assumption in the previous section — there is no endogenous fiscal instrument that can shift this relation either. The central bank's ability to achieve its inflation and output-gap stabilization objectives is accordingly more tightly constrained.

Indeed, as Sims (2005) notes, full price stability (or even complete stabilization of the inflation rate at some non-zero value) will typically be *infeasible* under these assumptions — unlike the situation considered in the previous section, where this is a possible monetary policy, though not quite the optimal one. Condition (1.11) allows one to easily derive the unique output-gap process consistent with complete stabilization of the inflation rate; but the process $\{y_t\}$ obtained in this way (together with the assumed constant inflation rate and the exogenously given tax process) will almost surely *not* also satisfy the intertemporal solvency condition (1.12), for all possible realizations of the disturbances that affect the fiscal stress term f_t. This does not, however, mean that monetary policy is powerless to stabilize either nominal or real variables. While one cannot commit to completely stable inflation both immediately and for the indefinite future, there remains a choice among alternative paths for inflation, some of which involve inflationary spirals of the sort modeled by Loyo, and others of which involve a return to price stability fairly quickly. Here we con-

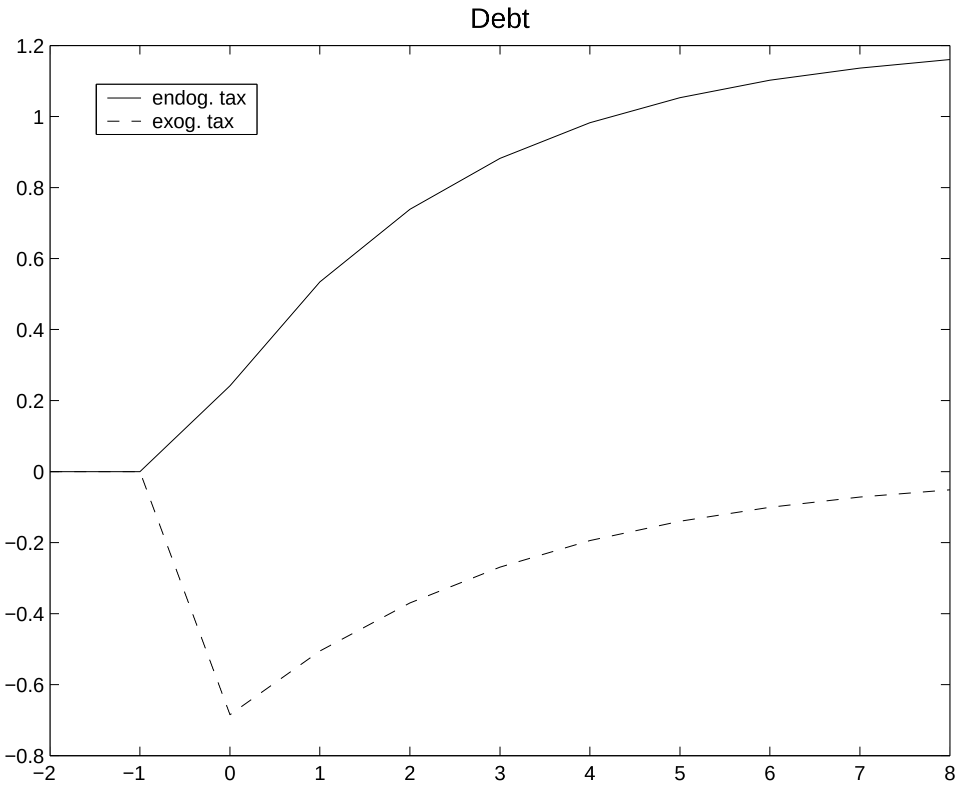

Figure 6: Impulse response of the public debt to a pure fiscal shock under optimal monetary policy, under two alternative assumptions about tax policy.

sider the central bank's optimal choice among the set of possible equilibria, given the constraints implied by exogenous fiscal policy.

The optimization problem in this case is to find paths $\{\pi_t, y_t\}$ that minimize (1.9) subject to the constraints (1.11) and (1.12), in which we now treat $\{\hat{\tau}_t\}$ as another exogenous disturbance process. The first-order conditions for this optimization problem are again the same conditions (3.3) – (3.5) as before. The only difference is that (3.6) need no longer hold (as the tax rate need not be chosen optimally); this condition is replaced by the exogenously given process $\{\hat{\tau}_t\}$.

Optimal state-contingent responses to exogenous disturbances of various types can easily be derived in this case, using the same methods as in the previous section. For purposes of illustration, we again consider the case of a "pure fiscal shock," by which we mean an exogenous increase in the size of government transfer programs, and to simplify our figures we present results only for the case $\rho = 0.7$. Figure 6 shows

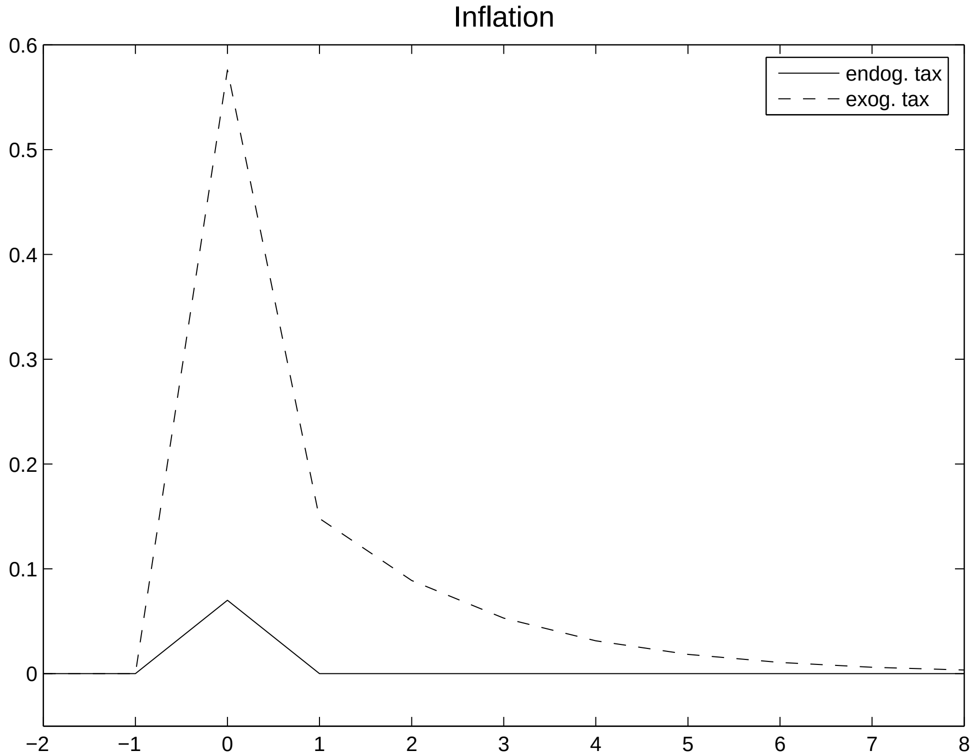

Figure 7: Impulse response of the inflation rate, under the same two assumptions about policy.

the impulse response of the real public debt to such a shock under optimal monetary policy, both under the assumption that tax policy also responds optimally (as in the previous section) and under the assumption that the path of the tax rate *does not respond at all.* (The former case is shown by the solid line, which is the same as in Figure 3; the latter case is shown by the dashed line.) Figure 7 shows the impulse response of the inflation rate under optimal monetary policy, under the same two possible assumptions about fiscal policy.

As Figure 7 indicates, the degree to which it is optimal to allow a fiscal shock to affect the inflation rate is much greater in the case that tax policy cannot be expected to adjust in response to the shock. The optimal immediate effect on the inflation rate is about 8 times as large, in our calibrated example, in the case of the exogenously given path for the tax rate; and it is also slightly more persistent, so that the inflation rate expected over the next few quarters should be allowed to rise slightly in response to such a shock. The larger immediate increase in inflation means that reduction of the real burden of the public debt through unexpected inflation plays a bigger role in offsetting the fiscal stress in this case. This is necessary because under the assumption of an exogenous path of taxes, the long-run level of the real public debt *cannot* be increased (as would occur under the optimal fiscal policy); instead, it must continue to equal the unique level consistent with intertemporal solvency given the expected long-run tax rate. As shown in Figure 6, the level of the real public debt must *fall* in response to the fiscal shock, rather than rising, so that it can approach its unchanged long-run level *from below.* (The real public debt must be expected to grow over the quarters in which the size of transfer programs is still temporarily high, but this is no longer a surprise.) This can occur only through a sufficiently large surprise increase in inflation in the quarter in which the shock occurs, just as under the optimal policy for the flexible-price economy analyzed by Chari and Kehoe (1999).

Nonetheless, even under this extreme assumption about the non-responsiveness of tax policy, an optimal monetary policy does not involve too great an increase in inflation in response to a disturbance that increases fiscal stress. In the case of the shock considered in Figure 7, the cumulative increase in the price level is still only about a quarter of a percentage point, whereas the price increase under optimal policy for the flexible-price economy would be about six times as large. Even when tax increases do not contribute to relieving fiscal stress at all, less inflation is required to maintain intertemporal solvency in the case of a sticky-price economy, because inflationary policy stimulates real activity, and the resulting higher real incomes imply higher tax revenues, that contribute substantially to government solvency in the equilibrium shown by the dashed lines in Figures 6-7.

This illustrates an important benefit of an appropriate managed inflation targeting regime, even in an economy in which fiscal policy is purely exogenous, as assumed in the pessimistic case considered by Sims. The central bank is able to maintain intertemporal solvency without too much inflation in our example exactly because *inflationary expectations are contained* even while a transitory inflation is allowed to erode the real value of existing nominal claims on the government. If expected inflation does not increase much at the time of the fiscal shock, the aggregate-supply tradeoff (1.11) implies a relatively large increase in real output for a given size increase in the current inflation rate, and so a substantial improvement in government solvency can be obtained without too much inflation. If, instead, the expected future inflation rate were to rise as much as the current inflation rate (or even more), the increase in real activity resulting from inflationary monetary policy would be tiny, or non-existent, or even of the opposite sign. In that case tax revenues would increase little if at all, and all of the fiscal stress would have to be offset through a reduction in the real value of the public debt due to unexpected inflation; the required immediate increase in inflation would then be many times larger.

We can illustrate this tradeoff quantitatively by considering alternative possible responses to a disturbance to the fiscal stress.[19] Suppose that in response to such a shock in period t, monetary policy allows the path of inflation to change in such a way that

$$E_t\pi_{t+j} - E_{t-1}\pi_{t+j} = \tilde{\pi}_t\lambda^j$$

for all $j \geq 0$, for some initial inflation response $\tilde{\pi}_t$ and some persistence factor $0 \leq \lambda \leq 1$. In addition, suppose for simplicity that the disturbance does not change the expected path of the tax gap $\{E_t[\hat{\tau}_{t+j} - \tau^*_{t+j}]\}$.[20] For any choice of λ, there exists a unique value of $\tilde{\pi}_t$ (given the size of the shock at date t) such that this represents a possible equilibrium response under a suitable monetary policy. We can then consider how $\tilde{\pi}_t$, and hence the entire path of the inflation response, varies with the choice of λ.

Solving (1.11) for the implied response of the output gap, we find that

$$E_t y_{t+j} - E_{t-1}y_{t+j} = \frac{1-\beta\lambda}{\kappa}\tilde{\pi}_t\lambda^j$$

for each $j \geq 0$. Substituting this and the conjectured inflation response into the intertemporal solvency condition (1.12), we find that the condition is satisfied if and only if

$$\tilde{\pi}_t = \frac{\tilde{f}_t}{1 + \sigma^{-1}(1-\beta\lambda) + (1-\beta)b_y/\kappa}. \tag{4.1}$$

This indicates how the initial effect on inflation relates to the expected degree of *persistence* of the effect of the shock on the inflation rate. A higher value of λ makes the denominator of (4.1) a smaller positive quantity, meaning that $\tilde{\pi}_t$ must be *larger*.

[19] This might be the pure fiscal shock considered in the numerical examples presented thus, but it might also be any other kind of exogenous disturbance that affects the term f_t.

[20] In the case that the path of the tax gap also changes, a derivation like the one sketched below is again possible, except that in the numerator of (4.1), instead of $\tilde{f}_t$ one has $\tilde{f}_t$ plus a multiple of the present value of changes in the expected tax gap. The conclusions obtained below about the way in which $\tilde{\pi}_t$ depends on the value of λ continue to apply.

Thus a policy that makes the effect of the shock on inflation more persistent will involve a larger initial effect on inflation, as well as (*a fortiori*) a larger effect on inflation at all later dates.

It is thus important, even under the constraints assumed in this section, for the central bank to credibly commit itself to *restore low inflation relatively soon* following a disturbance that creates fiscal stress. This requires both that monetary policy be clearly focused on inflation control, and that the central bank's commitment to an essentially constant medium-term inflation target be unwavering, even when fiscal stress requires a short-run departure from the medium-term target. The credibility of such a commitment will be greater, of course, to the extent that the central bank is able to explain why the size of departure that is currently occurring is consistent with the principles to which it is committed, rather than representing an abrogation of those principles or a concession that they are frequently inapplicable. We next consider the formulation of a more flexible form of target criterion that would be suitable for this purpose.

5 An Optimal Targeting Rule for Monetary Policy

We have argued that even in the case of severe constraints of the degree to which an optimal adjustment of tax policy can be expected, an optimal monetary policy will involve a commitment not to allow temporary increases in inflation to persist, so that medium-term inflation expectations remain well-anchored. However, it may be asked what kind of commitment regarding the future conduct of monetary policy would serve this purpose, without appearing to promise different conduct in the future than the kind that is exhibited in the present — a type of promise that would not easily be made credible.

The answer, in our view, is that monetary policy should be conducted in such a way as to seek at all times to conform to an appropriately formulated *target criterion*. The target criterion should both explain how much inflation can be allowed in the short run, in response to a given type and size of disturbance, and guarantee (if it is expected to be followed in the future as well) that there will be no significant fluctuations in the inflation rate that should be forecasted more than a few quarters into the future.

Can one find a criterion that will serve this purpose, under each of the variety of assumptions about the fiscal regime that we have considered above, and for all of the different types of disturbances that might affect the economy? In fact we can, using the same method as was illustrated in section 2, namely, the use of the first-order conditions that characterize optimal policy to derive a target criterion that must be satisfied in an optimal equilibrium.[21] Because conditions (3.3) – (3.5) must hold if monetary policy is optimal, under all of the fiscal regimes considered thus far,[22] a target criterion that follows from (and in turn guarantees) these conditions will be a criterion for the optimality of monetary policy that will be generally useful. Since the first-order conditions also apply regardless of the nature of the (additive) exogenous disturbances that may perturb the model structural relations, the resulting criterion is also robust to alternative assumptions about the statistical properties of the disturbances, as stressed by Giannoni and Woodford (2002).

A robustly optimal target criterion that is equivalent to demanding that there exist Lagrange multiplier processes $\{\varphi_{1t}, \varphi_{2t}\}$ that satisfy (3.3) – (3.5) can be formulated as follows. As in the simpler case treated in section 2, optimal policy can be described in terms of commitment to a target for the output-gap-adjusted price level $\tilde{p}_t$ defined in (2.4). The central bank should use its policy instrument to ensure that each period, $\tilde{p}_t$ satisfies

$$\tilde{p}_t = p^*_{t-1} + (1+\eta)(p^*_t - p^*_{t-1}), \tag{5.1}$$

where

$$\eta \equiv \frac{\sigma^{-1}}{(1-\beta)b_y + \kappa} > 0,$$

and p^*_t is the central bank's estimate (conditional on information at t) of the *long-run* (output-gap-adjusted) price level *consistent with intertemporal government solvency*.

Implementation of policy in accordance with this criterion would require the central bank to estimate the current value of the long-run price-level target p^*_t as part of each decision cycle. This would be determined, in principle, in the following way. One observes that (5.1) implies that

$$E_t \tilde{p}_T = p^*_t$$

[21]Further details of the derivation are given in Benigno and Woodford (2005b), where we also discuss the form of targeting rule that is appropriate under a broader class of possible assumptions about fiscal policy.

[22]Note that these same conditions also hold in the case that lump-sum taxes exist, as assumed in section 2. But in that case we also have the condition that $\varphi_{2t} = 0$ at all times, which allows the first-order conditions to be reduced to the system (2.2) – (2.3).

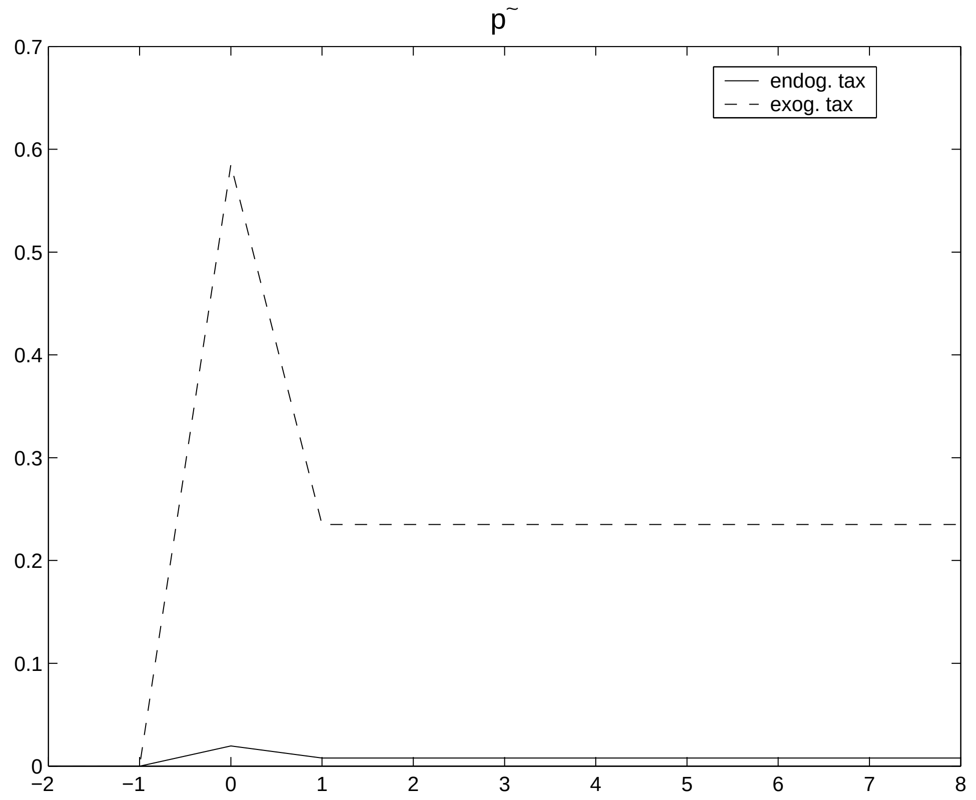

Figure 8: Optimal response of the output-gap-adjusted price level $\tilde{p}_t$ under the two polar assumptions about fiscal policy.

for all $T \geq t+1$. Thus a value for p_t^* implies not just a value for $\tilde{p}_t$, but a complete expected path $\{E_t\tilde{p}_T\}$ for all $T \geq t$. The central bank's model of the economy — including its model of the behavior of the fiscal authority — can then be used to derive the implied forecast paths for the other endogenous variables corresponding to a given current estimate of p_t^*. The right estimate of p_t^* is then the one that leads to a set of forecast paths consistent with intertemporal government solvency.

The degree to which p_t^* will be found to increase in response to a given disturbance will depend on the nature of the fiscal regime. For example, Figure 8 shows the optimal responses of the path of the output-gap adjusted price level in the case of both an endogenous (optimal) and an exogenous path for the tax rate, for the same kind of real disturbance as in Figures 6 and 7. One notes that in both cases, the *shape* of the optimal response of this variable is the same; the response in each case is simply scaled in proportion to the different size jump in the long-run price level.[23] The same would be equally true if we were to plot optimal responses to other types of exogenous disturbances, or if we assumed a different degree of persistence of the disturbance; this is the feature of optimal policy that allows such a simple target criterion to provide a robust guide for policy. The same kind of criterion applies as well in the case that lump-sum taxes exist, as assumed in section 2; but in this case, there is never any need to vary the long-run price-level target in order to ensure solvency, and so (5.1) applies with p_t^* equal to a constant p^*.

Implementation of this kind of targeting procedure requires the central bank to make projections, not only of the future evolution of prices and real activity, but also of the evolution of the government finances and the public debt, so as to evaluate the consistency of alternative monetary policies with intertemporal government solvency. Some may fear that this sounds like a prescription for exactly the sort of "fiscal dominance" of monetary policy against which Fraga *et al.* (2003) warn. It is true that we have described a regime under which monetary policy could be conducted in a constrained-optimal way, even if the fiscal authority were understood to be completely unwilling ever to adjust fiscal instruments in order to maintain intertemporal solvency. However, the knowledge that the central bank reasons in this way should not provide an incentive for the fiscal authority to be profligate, relying upon the central bank to adjust monetary policy as necessary in order to accommodate any degree of spending. Under the regime proposed here, the central bank would make *its own judgment* regarding the degree of fiscal adjustment that could properly be expected, given the constraints under which fiscal policy is expected to be determined, and then target a path for the output-gap adjusted price level accordingly. It would be appropriate for the central bank to publicize the projections on the basis of which this decision is made. Among other things, this would make clear to the fiscal authority what degree of eventual revenue increases are being counted upon by the central bank, and will be necessary in order for intertemporal solvency to be maintained, given the central bank's target path for the gap-adjusted price level.

[23] Benigno and Woodford (2005b) show that the same is true in the case that the tax rate is predetermined for a certain period of time, after which it adjusts optimally. In such a case, the size of the response is intermediate between the two cases shown in Figure 13.

6 Conclusions

The nature of fiscal policy has important consequences for the optimal conduct of monetary policy, for two reasons. On the one hand, monetary policy has consequences for the intertemporal solvency of the government under a given fiscal policy, and so a change in monetary policy can require corresponding changes in fiscal policy, that will have welfare consequences if only distorting sources of government revenue exist. And on the other hand, fiscal policy decisions generally have supply-side consequences that affect the available tradeoff between inflation stabilization and the central bank's ability to stabilize the welfare-relevant output gap. Hence alternative assumptions about the set of instruments available to the fiscal authority and the flexibility and accuracy with which they will be adjusted can greatly change the complexity of the challenges involved in monetary stabilization policy.

Nonetheless, we have argued that it is possible to prescribe an optimal approach to the conduct of monetary policy that is applicable to a range of different assumptions regarding fiscal institutions and the character of fiscal policy. And while the problem of monetary stabilization policy is likely to be more complex, under realistic assumptions about fiscal policy, than in familiar analyses that abstract altogether from interactions between monetary and fiscal policy decisions, we found that even under considerably more general assumptions, an optimal monetary policy has important aspects of a flexible inflation targeting regime.

Under all of the regimes considered, optimal monetary policy can be implemented through a commitment to use policy to guarantee fulfillment of a *target criterion,* which specifies the acceptable level of an output-gap-adjusted price level given the central bank's current projections regarding the economy's possible future evolution. A credible commitment to such a rule should serve to anchor inflation expectations. As we have seen, commitment to the target criterion implies that there should be *no forecastable variation in the rate of growth* of the output-gap adjusted price level over any horizons beginning a quarter or further in the future; this means that any variations in the inflation forecast that occur must be fully justifiable in terms of the projected change in the output gap over the same horizon. Moreover, since forecastable changes in the output gap over periods in time more than a few quarters in the future will always be negligible, this implies that medium-term inflation forecasts must be essentially constant.

Thus an important feature of an optimal policy commitment will be a credible commitment by the central bank to return inflation to its long-run target level fairly promptly after any unforeseen disturbance that justifies a temporary departure from that target. We have seen that, when the set of available fiscal instruments is fairly constrained, it *is* important to allow for temporary variations in the inflation rate in response to exogenous disturbances; and disturbances that affect the economy mainly through their impact on the government budget will be among the types of disturbances that ought to be allowed to have a transitory effect on the inflation rate. But even while the central bank allows such disturbances to affect the current rate of inflation (and even, its current target for the gap-adjusted price level), it should stress the fact that the size of the one-time effect on prices that is allowed is one that is calculated to be consistent with a prompt stabilization of prices again. Thus the development of an explicit calculus that can be used to justify temporary departures from the inflation target that would have been maintained in the absence of the shock is an important project, in order to adapt the practice of inflation targeting to the circumstances of countries with frequent and urgent fiscal imbalances.

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