

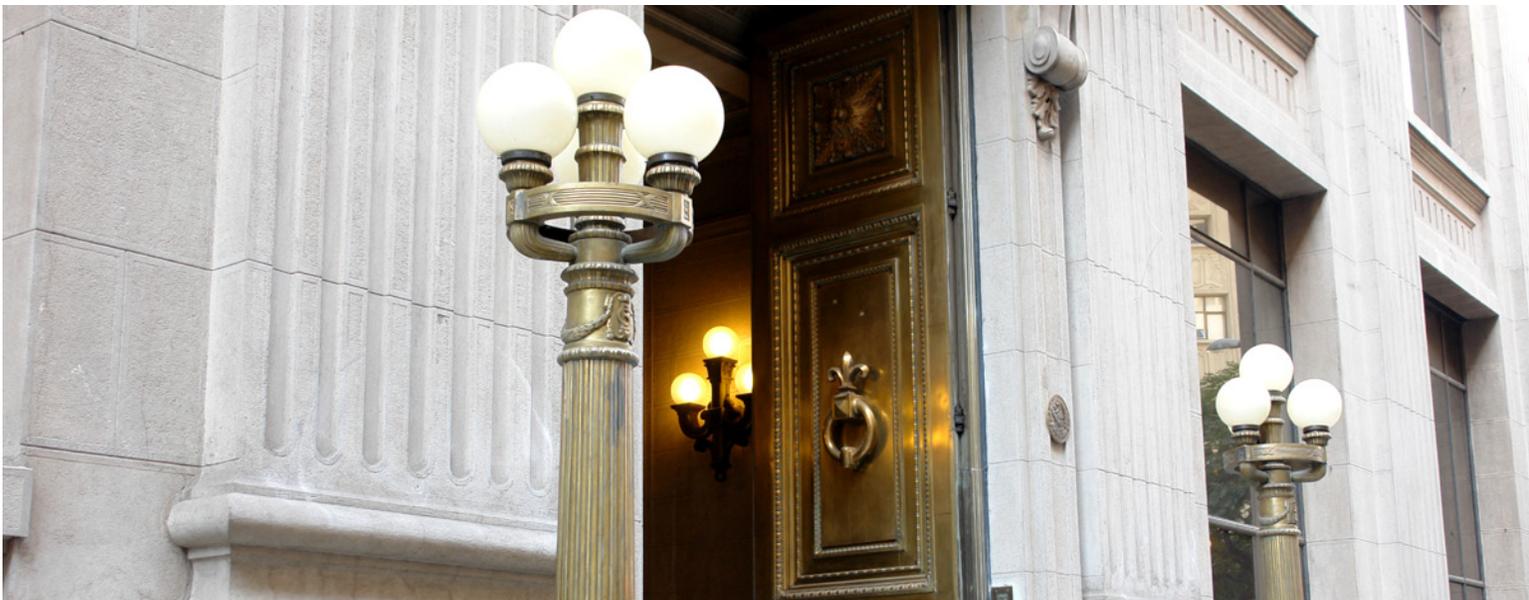
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Robert King
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Documentos de Trabajo del Banco Central de Chile
Working Papers of the Central Bank of Chile
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POLICY DESIGN WITH PRIVATE SECTOR SKEPTICISM IN THE TEXTBOOK NEW KEYNESIAN MODEL *

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Abstract

How should policy be optimally designed when a monetary authority faces a private sector that is skeptical about policy announcements and makes inferences about the monetary authority's ability to follow through on policy plans from economic data? To provide an answer to this question, we extend the standard New Keynesian macroeconomic model to include imperfect inflation control and Bayesian learning by private agents about whether the monetary authority is a committed type (capable of following through on announced plans) or an alternative type (producing higher and more volatile inflation). We find that the optimal pattern of inflation management depends critically on how skeptical the private sector is and how it views the alternative monetary authority whether the latter is just mechanically more inflationary or if it would mimic the committed monetary authority's actions.

Resumen

¿Cómo podría diseñarse un plan de política monetaria cuando el sector privado se muestra escéptico ante los anuncios de dicho plan y hace inferencia usando datos económicos respecto a la habilidad del Banco Central para seguir dicho plan? Para responder esta pregunta, este artículo extiende el modelo neo-keynesiano estándar para incorporar control imperfecto de la inflación por parte de un Banco Central y aprendizaje bayesiano del sector privado respecto al tipo del Banco Central. Estos tipos pueden ser “comprometido” (decidido a seguir sus anuncios de política) y “alternativo” (que produce inflación más alta y volátil que el comprometido). Este artículo encuentra que el manejo óptimo de la inflación depende crucialmente de cuán escéptico es el sector privado y de cómo ve al tipo alternativo como uno que mecánicamente induce mayor inflación o si imitaría las acciones de un Banco Central comprometido.

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1 Introduction

Policy design in modern dynamic stochastic general equilibrium models with nominal frictions is conducted in one of two modes: the monetary authority is fully capable of commitment or completely unable to commit. In both cases, there is an implicit assumption that the private sector knows whether policymakers possess or lack the ability to commit. This knowledge, however, cannot be taken for granted, as ability to commit is by nature unobservable. A large literature has been devoted to designing apparatus for policymakers to communicate with the private sector about their ability to commit.¹ In practice, central banks have also provided various means for private analysts to compare inflation outcomes and inflation announcements.² But how should a committed policy be designed when the private sector is *not* informed about the policymaker's ability to commit?³ In other words, if the private sector distrusts the policymaker and makes inferences about the policymaker's ability to follow through on policy plans from economic data, what is the best way to restore trust?

In this paper, we provide a reference answer to this question by studying a version of the textbook New Keynesian monetary policy model of linear quadratic form that is commonly used to represent the rich macroeconomic dynamics of medium-scale policy models in a simplified manner. We draw a distinction between the ability to commit – possessed by a committed monetary authority that can formulate and implement the type of detailed plan derived in a commitment equilibrium – and the credibility of commitment. We derive the optimal policy plan for an authority that can commit but faces a skeptical private sector which attaches an execution probability – an extent of credibility – to that plan yet also believes that the policy may be selected according to an alternative plan that is more

¹See the works of Dixit (2001), Lohmann (1992), Herrendorf (1998), Lockwood (1997), Svensson (1997), Walsh (1995, 2002) and Woodford (2003a), among many others.

²Examples include inflation reports, the release of the minutes of board meetings, and the publication of the central bank's forecasts.

³As most monetary authorities believe that their policy plans will be implemented, they tend to use some version of the commitment solution as a guide to the design of policy.

inflationary. The committed authority also recognizes that (i) actual inflation outcomes are more variable than its policy choices due to implementation errors, and (ii) private agents learn from inflation outcomes about the nature of the authority that is in place. We provide a recursive formulation of the optimal policy problem, building on the work of Marcet and Marimon (1998, 2011), and Khan, King and Wolman (2003).

Within the well-known full commitment case, in which the dynamic policy plan is fully credible, this model has two striking features.⁴ First, the optimal policy involves an initial interval of high but declining inflation that stimulates real economic activity, which we term the "startup" phenomenon. Second, the optimal policy accommodates a significant amount of inflation shocks to offset the impacts on real economic activity.

To explore whether these implications of the full credibility case carry over to a setting with imperfect credibility, we use two specifications for the alternative policy plan followed by an alternative type of monetary authority. In our benchmark case, the alternative monetary authority adopts the simple rule given by the complete information equilibrium without policy commitment, which is well understood to involve both inflation bias and stabilization bias. In the other case, the alternative monetary authority's policy adds a "time-varying inflation premium" to the committed policy. Thus, we call this case the "tag-along" case. This latter case is motivated by the important literature on the credible control of inflation that emerged in the 1980s,⁵ which stressed that monetary authorities not capable of full commitment might be induced to mimic the behavior of a committed monetary authority – more specifically, a low inflation policy – by the force of trigger-strategy expectations or reputation concerns.⁶ The assumed "tag-along" behavior of the alternative monetary authority is our initial exploration of the potential consequences of such mimicking as described in the

⁴See, for example, Clarida, Gali, Gertler (1999) and King and Wolman (1999)

⁵Barro and Gordon (1983), Barro (1986), and Backus and Driffill (1985a,b)

⁶A recent contribution to the reputation literature by Cripps, Mailath and Samuelson (2004) shows that the introduction of imperfect monitoring in an infinite-horizon game undermines the incentive of a weak monetary authority to mimic a committed monetary authority in the long run. However, mimicking can still be a short-run phenomenon. In addition, long-run mimicking behavior can be restored if the type of the long-lived player is determined by a stochastic process. See, for example, Mailath and Samuelson (2001).

literature.

In the benchmark case, we find notable departures from standard conclusions about the startup phenomenon. For all levels of credibility, the optimal policy features an initial interval of inflation lower than that under the full commitment solution, with the nature of the path depending on the private sector's initial extent of skepticism but frequently involving deflation. Essentially, the monetary authority engages in an initial period of *reputation building*.^{7,8} Thus, in our benchmark analysis, rapid disinflation is optimal and gives rise to a recession, whose depth is greater when the initial reputation of the monetary authority is weaker.

When the alternative monetary authority is modeled as adopting tag-along behavior, we find that the startup inflation is restored as part of the optimal policy. Given a strong initial reputation, the optimal policy for the committed monetary authority closely resembles the full commitment solution: there is positive but declining inflation, with an initial interval of real stimulus. Given a weak initial reputation, the optimal policy also involves an initial interval of high but declining inflation, but the disinflation policy is so aggressive that it results in a u-shaped recession in the real economy.

In the late 1970s and early 1980s, there was much debate about the appropriate strategy for achieving disinflation in the United States and other countries. One approach was *gradualism*, whereby policy would reduce inflation slowly, with the objective of producing small real losses. Another approach was to trigger rapid disinflation, which was frequently called the *cold turkey* strategy.⁹ The "startup" phenomenon in the full commitment solution of the New Keynesian model suggests that a newly reorganized monetary authority with full

⁷Generally, the credibility of an inflation plan is the likelihood that the plan will be executed, whereas reputation is the likelihood that the monetary authority is the committed type. In the present model, the credibility of the inflation plan and reputation for commitment are identical.

⁸The precise implications of this reputational investment for the optimal policy depend on the structure of the economy, including the learning rule of the private sector, so that there is no simple, comprehensive prescription like that found under the "timeless perspective" advocated by Woodford (1999). Kurozumi (2008) and Loisel (2008) study whether the optimal monetary policy is sustainable in the sense of Chari and Kehoe (1990) using a different notion of reputational equilibria.

⁹These two strategies are discussed, for example, by Sargent (1982) and Bernanke (2004).

commitment and credibility would adopt a gradualist policy, with a resulting boom in real economic activity. Our analysis sheds new light on the debate by arguing that the nature of the optimal disinflation should depend on the reputation of the monetary authority and on how the private sector views the behavior of the alternative monetary authority.

We also examine how evolving credibility/reputation leads policy and macroeconomic activity to respond to inflation shocks in a time-varying manner. There are two kinds of inflation shocks in our model: implementation errors, which correspond to missed inflation targets; and cost-push shocks, which correspond to energy shocks. Thus, our setup allows us to address two important questions in the New Keynesian literature and in practical monetary policy design: (1) how should a monetary authority optimally respond to departures of inflation from its target and (2) what are the effects of energy price shocks on policy and real activity?

In the New Keynesian literature, discussions over these two questions often involve whether the central bank acts under commitment or discretion.¹⁰ Thus, we explore impulse responses to one-time implementation errors and persistent cost-push shocks along two dimensions: (i) the optimal policy takes into account the interaction between shocks and policy actions, as it affects agents' learning; and (ii) the extent of "stabilization bias" is affected by the evolving degree of credibility.

A positive one-time implementation error lowers the authority's reputation. In the case with a benchmark alternative monetary authority, we find that policy responds aggressively to rebuild reputation through a protracted interval of deflation after initially accommodating the implementation error. Reputation will improve more rapidly if the authority's initial reputation is weaker. Due to the reputation building, the optimal policy approaches the standard full commitment solution fairly quickly.¹¹ When the alternative monetary authority displays tag-along behavior, the committed policy loses its effect on the private sector's

¹⁰See, for example, Svensson (1999) and Vestin (2006) on the relative merits of price-level targeting and inflation targeting.

¹¹A deflationary interval and rapid learning are also obtained by Cogley, Matthes and Sbordone (2011) in substantively related research that uses a different computational approach.

learning but still responds to the evolving degree of reputation. Deflation occurs only when the authority's initial reputation is weak, and for a different reason: it is now a part of the disinflation policy that is implemented to counter the adverse effect of a deteriorated reputation on output.

A positive and persistent cost-push shock, however, improves the committed monetary authority's reputation. When the initial reputation is already strong, the reputation gain is small, in which case the committed authority responds with similar policies regardless of how the alternative authority is specified. When the initial reputation is weak, a large gain in reputation induces the committed authority to respond with policies that are much more accommodative if the alternative authority displays tag-along behavior than if it does not, because in the former case, the committed authority is not constrained by the effect of its policies on learning.

We also explain why our optimal solution would be observationally equivalent to the outcome of a particular interest rate rule for monetary policy. We explore the types of variables that a time series econometrician would be led to incorporate into an empirical study of such an interest rate rule and provide a somewhat speculative reinterpretation of inflation implementation errors as shocks to the interest rate rule.

This is not the first paper to distinguish the ability to commit from the credibility of commitment. The reputation literature on monetary policy, of which Barro (1986) and Backus and Driffill (1985a,b) are representative examples, shows that reputation can motivate a discretionary policymaker to keep inflation low. However, the committed policy is exogenous in these models. Barro (1986) notes this shortcoming: "Zero inflation is optimal with the assumed cost function if commitments are not only made but are also fully believed. In the present context credibility is tempered by the possibility that the policymaker is type 2. In this case the best value to commit to need no longer be zero inflation" (page 17). In response to this concern, Cukierman and Leviatan (1991) and King, Lu and Pasten (2008) derive the optimal committed monetary policy under imperfect credibility. However, both

papers adopt the Barro-Gordon Phillips curve, which is not forward-looking. As the New Keynesian Phillips curve has been widely adopted in the modern macro literature, this paper incorporates this forward-looking constraint and presents a recursive method that can be used to solve the model.

Another branch of the literature, developed by Roberds (1987) and recently extended by Schaumburg and Tambalotti (2007) and Debortoli and Nunes (2010, 2012), offers the "loose commitment" approach. This approach also relaxes the full commitment assumption by assuming that in each period, there is an exogenous probability that a committed policymaker will be replaced, so that the policy plan will be reoptimized. However, the credibility of the policy plan in our model is endogenously determined by private agents' Bayesian learning and our optimal committed policy design takes into account the interaction between policy and learning.

The organization of the paper is as follows. In section 2, we describe our variant of the textbook New Keynesian model and present the recursive optimal policy problem. In section 3, we study the optimal inflation policy and its implications for other macro variables when a committed monetary authority, without pre-existing commitment, gets a new chief. Section 4 examines the optimal policy in response to a missed inflation target and a persistent cost-push shock. In section 5, we explore alternative interpretations of our equilibrium outcomes. Finally, section 6 concludes and gives an overview of planned future work.

2 The Model

2.1 The standard New Keynesian problem

A standard New Keynesian (NK hereafter) optimal policy problem involves a monetary authority maximizing an expected present discounted value objective

$$\max_{\{\pi_t, x_t\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t u(\pi_t, x_t) \right\} \quad (1)$$

defined over inflation π and output x (relative to an efficient level x^*).

The momentary objective is assumed to be quadratic:

$$u(\pi_t, x_t) = -\frac{1}{2}[\pi_t^2 + h(x_t - x^*)^2] \quad (2)$$

with $h > 0$. Output is good and inflation is bad at small positive values of x and π in the sense that $u_\pi = -\pi < 0$ and $u_x = -h(x - x^*) > 0$.

The standard NK constraint is a forward-looking specification for inflation,

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t + \varsigma_t \quad (3)$$

for each period $t = 0, 1, \dots, \infty$. In this expression, as is also standard, we include a shock to inflation, ς_t , governed by an exogenous Markov process.¹²

2.2 The modifications

Working from the prior literature, we introduce several complications into this basic model.

2.2.1 Types of policymakers

We study the design of optimal policy by an authority that is capable of commitment, which we call the *committed type* ($\tau = 1$) for short. The committed type makes an optimal choice with respect to its inflation plans in period zero and commits to the plans for all subsequent

¹²We present the elements of this familiar model in a relatively succinct manner; Table 2.1 provides the reader with a list of notation and definitions. Note that these specifications of the model have four properties that are central to understanding the dynamic behavior of optimal policy. First, as stressed by Ball (1994), perfectly credible anticipated disinflation increases output (directly from (3)). Second, output in the economy is inefficiently low (there are losses $h(x_t - x^*)^2$ in the momentary objective (2)). Because of the combination of these two properties, it is desirable to have an initial interval of high but declining inflation as part of an optimal policy plan. Third, as stressed by Ball (1995), imperfectly credible disinflation can readily yield a contraction in output (an implication of (3)). For example, Goodfriend and King (2005) show that a gradual decline in inflation coupled with expectations that inflation will remain at a high initial level will lead to intensifying recession. Fourth, there are costs to both inflation and output deviations in (2). This last feature governs the efficient extent of initial "start up" inflation. It also circumscribes the response of the economy to inflation shocks (ς_t), implying that it is not desirable to fully stabilize either output or inflation.

periods. $a^{\tau=1}$ is used to denote the committed type's inflation actions in all periods that are specified by predetermined state-contingent optimal plans.¹³

The authority faces public skepticism about whether inflation will be generated by its actions or by those of an alternative type ($\tau = 2$), for which we explore two different mechanical behavioral specifications in order to capture elements suggested by prior work. First, consistent with the literature on equilibrium policy without commitment, we use a simple *benchmark alternative* specification that can capture inflation bias and stabilization bias¹⁴

$$a_t^{\tau=2} = \mu + \phi\varsigma_t. \quad (4)$$

Second, we use a *tag-along alternative*, which takes the form

$$a_t^{\tau=2} = a_t^{\tau=1} + \mu + \phi\varsigma_t.$$

This rule is chosen to simply and transparently represent the potential implications of policy mimicking as described in the 1980s literature on the credible control of inflation.

Both specifications can be expressed using $a_t^{\tau=2} = \omega a_t^{\tau=1} + \mu + \phi\varsigma_t$, with $\omega = 0$ corresponding to the benchmark alternative and $\omega = 1$ corresponding to the tag-along alternative.

2.2.2 Intra-period timing

At each period t , we assume that the cost-push shock ς_t is realized first. Knowing the realization of the shock ς_t , the monetary authority announces its current policy action $a_t^{\tau=1}$ according to the state-contingent inflation plan of the committed type. The authority then implements a policy action a_t^{τ} , which is not directly observable by private agents and may potentially differ from the announced one depending on the type of monetary authority. This

¹³There is a difference between plans and actions. A plan is a mapping from history to a particular action, so the same plan may result in different paths of actions depending on the realizations of shocks.

¹⁴As employed in the literature (see, e.g., Gali and Gertler (2007)), inflation bias is the higher average inflation rate that arises when policy is determined without commitment capability, whereas stabilization bias is the greater extent of the variability of inflation in response to shocks such as ς .

policy action results in an inflation outcome π_t in a stochastic manner, which will be specified later. After observing π_t , private agents form expectations about one-period-ahead inflation $E_t\pi_{t+1}$ and obtain an output gap x_t that is consistent with the Phillips curve. Figure 2.1 illustrates the timing of each period.

2.2.3 Policy announcement

Although it is not the main focus of this paper, the role of the policy announcement made by the monetary authority at the start of each period deserves attention. If the current monetary authority is the committed type, it will announce its planned action $a_t^{\tau=1}$, as the plan is ex-ante optimal and the committed type, by definition, has committed to this plan. If the current monetary authority is the alternative type, we assume that it will make the same policy announcement as the committed type. The rationale for imposing this requirement is that the equilibrium outcome obtained under this assumption is consistent with the equilibrium outcome in an explicitly modeled signaling game in which both the committed type and the alternative type are strategic message senders. A detailed study of the signaling equilibrium is beyond the scope of this paper (as the alternative type is not strategic in our model), but Lu (2013) establishes this equivalence result in a setup with a strategic alternative type.

2.2.4 Imperfect monitoring

In our model, period t inflation is generated stochastically according to

$$\pi_t = a_t^\tau + \varepsilon_t, \tag{5}$$

where ε_t is an i.i.d. implementation error with zero mean and finite variance.¹⁵ The action a depends on the monetary authority's type, τ , but the distribution of the implementation

¹⁵A similar structure with implementation error can be found in Atkeson and Kehoe (2006), Cukierman and Meltzer (1986), etc.

error does not.

In this way, realized inflation is a noisy signal of the implemented policy action, and the deviation of inflation from the policy action does not immediately reveal the identity of the policymaker. We make this modeling choice for two reasons. One is that we believe that this aspect of the model properly represents real monetary policymaking, as monetary authorities do not always have perfect control over policy outcomes due to unexpected shocks. The other reason is that imperfect monitoring allows for greater flexibility in modeling dynamics, as it avoids a discrete shift in beliefs if the actual policy action deviates from the planned one.

2.2.5 Reputation and credibility

Throughout the paper, we view private agents as forming inflation expectations with a degree of skepticism about whether inflation will be generated according to the monetary authority's announced plan $a_t^{\tau=1}$ or otherwise. The degree of skepticism can be captured by the private sector's assessment of the probability that the monetary authority is of type 1. We use ρ to denote this probability and refer to it as the reputation of the monetary authority. We assume Bayesian learning about the monetary authority's type. When the current inflation rate is observed, the private sector's assessment of the probability ρ_t (as of the start of period t) that the monetary authority is of type 1 is updated according to a Bayesian updating function b that will be detailed later:

$$\rho_{t+1} = b(\pi_t, \rho_t; a_t^{\tau=1}, a_t^{\tau=2}). \quad (6)$$

This probability also measures the credibility of the committed monetary authority's plans, as it determines the extent to which the policy plans can affect expected inflation:

$$E_t \pi_{t+1} = \rho_{t+1} E_t [\pi_{t+1} | a^{\tau=1}(s_{t+1})] + (1 - \rho_{t+1}) E_t [\pi_{t+1} | a^{\tau=2}(s_{t+1})]. \quad (7)$$

In this expression, if the monetary authority is of type 1, future inflation will be generated

by the action of the committed type (type $\tau = 1$) $a^{\tau=1}$ according to its optimal plan chosen in period zero, a plan that maps the as yet unspecified future state of the economy s_{t+1} to a policy action. If the monetary authority is of type 2, future inflation will be generated by the actions of the alternative type (type $\tau = 2$) according to an exogenous rule $a^{\tau=2}$ that may also depend on the future state of the economy s_{t+1} . From the perspective of private agents, the former event occurs with probability ρ_{t+1} , as agents form expectations after observing period-t realized inflation.

2.2.6 Expected inflation

Given the behavior of the alternative type, $a^{\tau=2} = \omega a^{\tau=1} + \mu + \phi \varsigma_t$, the private sector's inflation expectation is:

$$\begin{aligned} E_t \pi_{t+1} &= \rho_{t+1} [E_t \pi_{t+1} | a^{\tau=1}(s_{t+1})] + (1 - \rho_{t+1}) [\omega (E_t \pi_{t+1} | a^{\tau=1}(s_{t+1})) + \mu + \phi E_t \varsigma_{t+1}] \\ &= l_{t+1} [E_t \pi_{t+1} | a^{\tau=1}(s_{t+1})] + (1 - \rho_{t+1}) [\mu + \phi E_t \varsigma_{t+1}] \end{aligned}$$

with $l = \rho + (1 - \rho)\omega$ defined for convenience.

Note that $E_t \pi_{t+1} | a^{\tau=1}(s_{t+1}) = E_t a^{\tau=1}(s_{t+1})$, given that the expected implementation error is zero, so that l_{t+1} captures the degree of control that the monetary authority has over near-term expected future inflation, which we colloquially refer to as its *leverage* over expectations. Also note that a portion of near-term expected future inflation, $(1 - \rho_{t+1})[\mu + \phi E_t \varsigma_{t+1}]$, is beyond the control of the monetary authority.

2.3 Interaction of credibility and policy

Since the extent of policymaker reputation (ρ), or equivalently, the credibility of policy plans, will have major implications for the nature of optimal policy undertaken by a committed policymaker, it is useful to review the four model components through which credibility influences such outcomes. In doing so, we identify four channels of effect.

2.3.1 Effects of credibility on the trade-off

The inflation specification (3) implies that

$$\pi_t = \kappa x_t + \beta l_{t+1} [E_t a_{t+1}^{\tau=1}] + \beta(1 - \rho_{t+1})[\mu + \phi E_t \varsigma_{t+1}] + \varsigma_t. \quad (8)$$

Regarding the trade-off between inflation and output that constrains optimal policy, we should note that there is both a *level effect*, $\beta(1 - \rho_{t+1})[\mu + \phi E_t \varsigma_{t+1}]$, and a *slope effect*, $\beta l_{t+1} [E_t a_{t+1}^{\tau=1}]$, on the trade-off, with $l_{t+1} = \rho_{t+1} + \omega(1 - \rho_{t+1})$. Each of these effects influences the consequences of the current policy action $a_t^{\tau=1}$ or future policy actions such as $a_{t+1}^{\tau=1}$. Generally, higher credibility reduces the level effect and increases the slope effect. With a benchmark alternative policymaker ($\omega = 0$), the credibility variable is evidently relevant to the slope ($l_{t+1} = \rho_{t+1}$). However, if there is a tag-along alternative policymaker ($\omega = 1$), then there is no slope effect because $l_{t+1} = 1$ in all cases.

2.3.2 Evolution of endogenous credibility

The next two channels are reputation/learning effects, which operate through

$$\rho_{t+1} = b(\pi_t, \rho_t; a_t^{\tau=1}, a_t^{\tau=2}) = \frac{\rho_t \psi(\pi_t; a_t^{\tau=1})}{\rho_t \psi(\pi_t; a_t^{\tau=1}) + (1 - \rho_t) \psi(\pi_t; a_t^{\tau=2})},$$

where $\psi(\pi; a)$ denotes the probability of observing π , conditional on the policy action being a . A higher level of credibility ρ_t has a direct *level effect* on future credibility ρ_{t+1} .

The *marginal learning effect* of the action $a_t^{\tau=1}$ is more subtle, as it depends on the assumed relationship between $a^{\tau=1}$ and $a^{\tau=2}$. To see this, notice that if we assume that the implementation error is normally distributed, i.e., $\psi(\pi; a) = \frac{1}{\sigma} \exp(-\frac{(\pi-a)^2}{2\sigma^2})$,¹⁶ the learning

¹⁶We drop the factor $(2\pi)^{-1}$ in the normal pdf from the front of ϕ to avoid confusion with the inflation rate.

specification can be written as

$$\begin{aligned}
& b(\pi_t, \rho_t; a_t^{\tau=1}, a_t^{\tau=2}) \\
= & \frac{\rho_t}{\rho_t + (1 - \rho_t) \exp\left(\frac{[-2\varepsilon_t(a_t^{\tau=1} - a_t^{\tau=2}) + (a_t^{\tau=1} - a_t^{\tau=2})^2]}{-2\sigma^2}\right)} \text{ if } \pi_t = a_t^{\tau=1} + \varepsilon_t. \tag{9}
\end{aligned}$$

Our assumption for the benchmark alternative case is that $a^{\tau=2}$ is invariant to $a^{\tau=1}$. Under this assumption, a lower policy action serves to reduce the inflation outcome – for a given implementation error – and raise ρ_{t+1} . However, under our tag-along assumption ($\omega = 1$ implies $a^{\tau=2} - a^{\tau=1} = \mu + \phi\zeta$), there is essentially no marginal learning effect.

2.4 Recursive optimal policy problem

The standard textbook approach to determining the optimal policy is to attach a Lagrangian multiplier – say, γ_t – to the forward-looking constraint (3) to find the first-order conditions and thus to determine the optimal behavior of inflation and output by solving the resulting linear difference equation system under rational expectations (see Gali (2008), Walsh (2003) or Woodford (2003)).

In our analysis, we use recursive methods that also begin with Lagrangian multipliers, as in the work of Marcet and Marimon (1998, 2011) on dynamic contracts and that of Khan, King and Wolman (2003) on optimal monetary policy. Because the monetary authority takes the policy action before the inflation realization, whereas the private sector forms expectations after the actual inflation outcome, we can write the recursive policy problem in two stages.

Define the *interim value function* Ω via

$$\begin{aligned}
\Omega(\rho_t, \eta_t, \varsigma_t, a_t^{\tau=1}, \pi_t) = & \min_{\gamma_t} \max_{x_t} \{u(\pi_t, x_t) \\
& + \gamma_t (\pi_t - \kappa x_t - \varsigma_t) - \eta_t [l_t \pi_t + (1 - \rho_t) (\mu + \phi\varsigma_t)] \\
& + \beta EW(\rho_{t+1}, \eta_{t+1}, \varsigma_{t+1}) | \rho_t, \eta_t, \varsigma_t, a_t^{\tau=1}, \pi_t\} \tag{10}
\end{aligned}$$

with

$$\eta_{t+1} = \gamma_t \tag{11}$$

representing the evolution of the *pseudo-state variable* η in terms of the commitment multiplier γ and with

$$\rho_{t+1} = b(\pi_t, \rho_t; a_t^{\tau=1}, a_t^{\tau=2}) \tag{12}$$

required by (6). In addition, define the *initial value function* W as

$$W(\rho_t, \eta_t, \varsigma_t) = \max_{a_t^{\tau=1}} \int \Omega(\rho_t, \eta_t, \varsigma_t, a_t^{\tau=1}, \pi_t) dF(\pi_t | a_t^{\tau=1}), \tag{13}$$

where $F(\pi|a)$ is the distribution of inflation conditional on a given policy action.

We establish the appropriateness of this recursive system in King and Lu (2013). Appendix A briefly summarizes the derivations for our restricted setup, so we focus here on its economic content. The policy action,

$$a^{\tau=1}(\rho_t, \eta_t, \varsigma_t) = \arg \max_{a_t^{\tau=1}} \int \Omega(\rho_t, \eta_t, \varsigma_t, a_t^{\tau=1}, \pi_t) dF(\pi_t | a_t^{\tau=1}) \tag{14}$$

must be made by the monetary authority without perfect knowledge of its ultimate consequences for inflation, so that the form of (13) is intuitive. That is, the optimal inflation action is one that maximizes the expected objective, given that it determines the distribution of the uncertain inflation outcome.

After the realization of inflation, the monetary authority can take no direct action. However, the design of its optimal policy plan takes into account that its future actions will affect how expected inflation responds to the actual inflation outcome. In turn, the response of expectations governs how output responds to inflation given the forward-looking constraint (3). This is why the recursive policy problem of the monetary authority also involves the

optimization in (10), with the outcome being a pair of *contingency plans* for output

$$x(\rho_t, \eta_t, \varsigma_t, \pi_t) = x(\rho_t, \eta_t, \varsigma_t, a^{\tau=1}(\rho_t, \eta_t, \varsigma_t), \pi_t) \quad (15)$$

and for the commitment multiplier

$$\gamma(\rho_t, \eta_t, \varsigma_t, \pi_t) = \gamma(\rho_t, \eta_t, \varsigma_t, a^{\tau=1}(\rho_t, \eta_t, \varsigma_t), \pi_t) \quad (16)$$

that is attached to (3).¹⁷ The choice of the commitment multiplier γ is the vehicle by which the recursive representation captures the management of expectations, conditional on π_t .¹⁸

3 Transitional dynamics

In this section, we study the inflation policy that would be employed by a new committed monetary authority without pre-existing commitments, i.e., with an initial state $\eta_0 = 0$.

We explore the consequences of a policymaker having an inherited reputation ρ_0 at five alternative values: 0, .25, .5, .75, 1.¹⁹ We refer to $\rho_0 = 0.5$ as our fifty-fifty case. Panel A in each figure shows the sequence of monetary policy actions, a , taken by the committed policymaker at each date under the assumption that no implementation errors actually arise ($\varepsilon = 0$) and that no cost-push shocks occur ($\varsigma = 0$). The subsequent panels display expected inflation e (panel B), reputation/credibility ρ (panel C) and real output x (panel D). All of the equilibrium dynamics shown in this section and the next section are computed using the parameter values summarized in Table 2.1. Appendix C explains our calibration strategy.

¹⁷The right-hand side of these expressions gives the contingency plan derived from (10), which is conditional on an arbitrary action a . The left-hand side involves a short-hand expression that embeds an evaluation at its optimal level (14).

¹⁸In the current setting, the pseudo-state variable η_t could be replaced by $\gamma(\pi_{t-1})$, but we opt for the present notation, as it allows for a clear separation between the contingency plan $\gamma(\rho_t, \eta_t, \varsigma_t, \pi_t)$ and the manner in which the commitment multiplier serves as a state variable. To put it concretely, given $\eta_t = \gamma_{t-1}$, other elements of history, such as $\eta_{t-1}, \varsigma_{t-1}, \pi_{t-1}$, are irrelevant. Our notation is also consistent with the general framework of Marcet and Marimon (1998, 2011).

¹⁹Symbol references are 1(‘*’), .75(‘△’), .5(‘◇’), .25(‘▽’), 0(‘o’).

As is well known, the full commitment solution in the NK model implies that there should be an initial interval of high but declining inflation. The anticipated reduction in inflation stimulates real economic activity, which is desirable because steady-state output is inefficiently low ($x^* > 0$). It is also well known that zero long-run inflation is optimal under full commitment.

In this section, we explore three substantive model variations to illustrate how imperfect credibility and different views regarding the alternative type's behavior change the optimal policies from the standard NK prescriptions. We begin with a case in which credibility is exogenous and constant. We then allow for endogenous credibility and study the impact of private sector learning on optimal policy. Finally, we study the implications of a tag-along alternative type that mimics the committed type's policy actions.

Across all model variations, the full reputation ($\rho_0 = 1$) solutions are identical, as reputation remains fixed at its initial level. The solutions under full reputation replicate the basic features of the NK model with full commitment. Under the assumption that the alternative type is the benchmark case, the zero reputation ($\rho_0 = 0$) solutions are also the same with or without private sector's learning. We set the parameter values of μ and ϕ such that the zero reputation solution replicates the full discretion solution in the NK model in which there is a constant inflation bias along the transitional dynamics.²⁰ Because the solutions under full commitment and full discretion are well known, the analysis below focuses on initial conditions with interior ρ_0 .

3.1 Constant credibility

We begin by exploring optimal policy when there is constant credibility and the alternative type is the benchmark case following a more inflationary policy rule.²¹ Figure 3.1 shows the

²⁰In the case of a tag-along alternative, μ and ϕ are set equal to their values in the benchmark alternative case. Note that the zero reputation solution does not apply to the case of a tag-along alternative.

²¹Although the recursive approach is sufficiently general to be applied to economies without a quadratic momentary objective (2) or a linear forward-looking constraint (3), these additional assumptions allow us to derive an exact quadratic solution for the value functions Ω , W and an exact linear solution for the decision

equilibrium dynamics. The results reported for this case set a benchmark for our endogenous credibility analysis.

Lack of commitment occasions an inflation bias, as in many macroeconomic models. When $\rho = 0$, the inflation bias is $\mu = 1\%$ or approximately four percent per year. With ρ changing continuously between 0 and 1, the extent of this bias changes smoothly. Note that, in our fifty-fifty reference case of $\rho = .5$, steady-state inflation is positive and, in fact, above $.5 * \mu = 0.5\%$. The policymaker therefore over-accommodates the adverse shift in inflation expectations, $(1 - \rho)\mu$. As shown in Figure 3.1, this accommodation is a general result for all levels of credibility.

To examine why, note that the authority with partial credibility has a Phillips curve trade-off

$$\pi_t = \beta\rho E a_{t+1}^{\tau=1}(s_t) + \beta(1 - \rho)\mu + \kappa x_t + \varsigma_t.$$

Compared to the full credibility case, the authority faces a higher intercept of the trade-off ($\beta(1 - \rho)\mu$ rather than 0) as well as a worsened slope in terms of the effects of expectation management ($\beta\rho$ rather than β).

Therefore, with partial credibility, although there is also an interval of high but declining inflation at the startup, this interval is smaller in scale and shorter in duration due to the reduced leverage that the authority has over expected inflation. To put it differently, the inflation action is less serially correlated when the level of credibility is lower. In addition, the economy converges to a positive long-run inflation rate, with the long-run inflation rate depending inversely on the level of credibility.

During the 1980s, imperfect credibility was sometimes suggested as a reason for central banks to avoid disinflation. The exogenous credibility results are compatible with that view, as long-run inflation policy is adjusted to accommodate expectations.

rules a, γ, x under constant credibility, as shown in Appendix B.

3.2 Benchmark alternative type

As shown in Figure 3.2, the dynamics arising with endogenous credibility are remarkably different from those considered with exogenous, constant credibility, both in the short run and in the long run. All paths begin with a policy action below the one in the full reputation case and follow up with disinflationary actions that lead to periods of negative inflation before they converge to zero inflation in the long run.

Therefore, endogenous credibility overturns both key implications of the NK model studied in the previous subsection: start-up inflation is eliminated (when $\rho_0 = 0.25$) or mitigated, and there is no long-run inflation. The low inflation actions taken in the beginning of the disinflation episode are intended to build the monetary authority's reputation, which rises sharply in Panel C (for $\rho_0 = 0.5$ case, the reputation reaches $\rho = .9$ within a year). The ability of the monetary authority to invest in reputation means that it asymptotically chooses zero inflation rather than choosing a positive inflation rate in the constant credibility case.²²

Turning to the details of the transitional dynamics, we observe that expected inflation is dramatically affected by the endogeneity of reputation, as private agents understand that a committed authority will take difficult actions. Consider our fifty-fifty reference case. Panel B shows that expected inflation is much lower than its counterpart in the constant credibility case. However, with expected inflation always above actual inflation and with the extent of this difference evolving over time, there is a recession that is initially quite deep, as shown in Panel D (the output is approximately -6% , with a gradual recovery taking place over a year). The persistently low level of output reflects the difficult actions taken by the monetary authority and the skepticism with which private agents view these actions, a skepticism that is resolved only after approximately one year.

Policy paths with other levels of initial reputation follow patterns that are similar to that of the fifty-fifty case, with magnitudes depending on the reputation investment to be

²²A straightforward modification – which is a temporary unobserved replacement of the committed type by an alternative type – leads to perpetual learning. This modification is presently embedded in our computational code, and we plan to explore its implications at a later stage of research.

accomplished. If the monetary authority starts with a weak initial reputation, it invests more aggressively through lower policy actions at the cost of greater output loss. The policy's learning effect is evident from Panel C: over four quarters, reputation reaches almost the same level as in the fifty-fifty case. A stronger initial reputation, on the other hand, makes the optimal policy actions less restrictive than those in the fifty-fifty case and more similar to those in the full reputation case. Nevertheless, the "start up" phenomenon is mitigated and is followed by a protracted period of negative inflation actions. As a result, only the initial output response is positive, leading to a mild recession created by the monetary authority's reputation investment.

In summary, the startup inflation mechanism that explores the initial conditions and is intended to achieve a boom in the NK model is mitigated or overturned by imperfect and endogenous credibility. The optimal policy in our model with endogenous credibility and the benchmark alternative type is consistent with the "cold turkey" approach to disinflation that was advocated by Sargent (1982, 1983) – an approach that uses dramatic policy actions – as a means of building credibility/reputation for low inflation.

3.3 Diagnostic model variations

We have just seen that endogenous credibility can have substantial implications for the behavior of inflation and for real activity under optimal policy. To understand why, we now explore alterations to structural elements of our endogenous credibility model, including the analysis of "tag-along" behavior by the alternative policymaker.

As discussed at the end of section 2, credibility interacts with policy in two components of our model. First, credibility affects the influence of expected future policy in equation (8). Relative to the benchmark studied in the last subsection, we can restore the complete leverage that the monetary authority has by adjusting the value of ω to one in this equation.

For concreteness, let us call the value of ω in this equation ω_p , so that

$$\pi_t = \kappa x_t + \beta l_{t+1} [E_t a_{t+1}^{\tau=1}] + \beta (1 - \rho_{t+1}) [\mu + \phi E_t \varsigma_{t+1}] + \varsigma_t$$

where $l_{t+1} = \rho_{t+1} + \omega_p (1 - \rho_{t+1})$.

Second, the current policy action affects the evolution of credibility in the Bayesian learning rule in equation (9), but this effect does not occur if ω is set to one. For concreteness, call the value of ω in this equation ω_b , so that

$$b(\pi_t, \rho_t; a_t^{\tau=1}, a_t^{\tau=2}) = \frac{\rho_t}{\rho_t + (1 - \rho_t) \exp\left(\frac{[-2\varepsilon_t(a_t^{\tau=1} - a_t^{\tau=2}) + (a_t^{\tau=1} - a_t^{\tau=2})^2]}{-2\sigma^2}\right)}$$

where $a_t^{\tau=2} = \omega_b a_t^{\tau=1} + \mu + \phi \varsigma_t$.

Finally, if we set $\omega_p = \omega_b = \omega = 1$, then we obtain tag-along behavior. Using this approach, we thus study the three cases summarized in Table 3.1. The equilibrium dynamics are displayed in Figures 3.3, 3.4 and 3.5.

3.3.1 No effect of policy on learning

We begin by examining a variant of our basic endogenous credibility model that rules out the effect of policy actions on learning, a setup accomplished by setting the parameter $\omega_b = 1$ while keeping the parameter $\omega_p = 0$. Conceptually, this case is closely related to the constant credibility case, but there is one crucial difference: although credibility is unaffected by policy action, it is not constant over time; rather, it evolves according to the Bayesian learning rule. Panel C of Figure 3.3 shows that the evolution of reputation depends substantially on its initial condition.

Recall that there were two key aspects of our section 3.2 analysis of optimal policy with a benchmark alternative and endogenous credibility: the elimination of the "start up" interval of high inflation and the asymptotic elimination of inflation. This diagnostic experiment shows that the first of these does not occur when the effect of policy actions on learning is

eliminated. Policy is always more inflationary than the full reputation solution and is most inflationary for low credibility.

However, provided that $\rho_0 > 0$, reputation will asymptotically approach 1. Hence, zero long-run inflation is obtained in all cases. In the fifty-fifty case, the optimal policy is to reduce inflation from approximately 2.5% to approximately 0% over roughly one year, with inflation falling by approximately the same amount each quarter. Relative to the optimal policy path displayed in Figure 3.2, the elimination of learning means that (i) there is a slower reduction in inflation and (ii) there is no deflation. To put it differently, the diagnostic experiment in this subsection confirms our earlier assertion that policy concern about learning makes policy aggressive in Figure 3.2, both in terms of the speed of inflation elimination and the desirability of deflation as part of the optimal policy.

3.3.2 No loss of leverage on expected inflation

We next consider the reverse diagnostic experiment, eliminating the leverage loss from imperfect credibility (setting $\omega_p = 1$ so that $l_t = 1$ in every period) but maintaining the learning effect from section 3.2 (setting $\omega_b = 0$).

In isolation, strengthening the monetary authority's leverage over expected inflation makes it more desirable for the monetary authority to engineer a gradual reduction in inflation. Recall from section 3.1 that a permanent increase in credibility leads to a higher initial inflation rate – relative to the relevant steady state – and a more measured reduction in inflation. Examining the $\rho_0 = .25$ optimal policy path in Figure 3.4 and comparing it to that in Figure 3.2, we observe that greater leverage over inflation expectations leads to higher inflation in the early stages of the plan – approximately 0.5% rather than -0.75% – as well as a more rapid transition to an interval of deflation, where the latter is more severe with increased leverage. The greater leverage in Figure 3.4 leads to smaller output losses during the transition to price stability, but it does not eliminate these disinflation costs, as the level effect of imperfect credibility on the trade-off between inflation and output remains.

Taking both of our diagnostic experiments together, we find that the key mechanisms that determine the nature of the optimal policy in section 3.2 are 1) the costs of imperfectly credible disinflation due to the level effect of credibility on the inflation-output trade-off and 2) the desirability of investing in reputation due to the marginal learning effect of policy actions.

3.4 Tag-along alternative type

In this subsection, we suppose that the alternative monetary authority follows a tag-along behavioral rule of the form $a^{\tau=2} = a^{\tau=1} + \mu + \phi\varsigma_t$. Figure 3.5 shows that the impact of policy mimicking by the alternative type can be dramatic for the committed monetary authority: at all levels of initial reputation, the startup inflation is restored as part of the optimal policy. As shown in the diagnostic experiment of section 3.3.1, the startup inflation reappears because the tag-along nature of the alternative type eliminates the effect of the committed type's policy action on private sector's learning.

Unlike in section 3.3.1, mimicking by the alternative type implies that the committed type, regardless of its initial reputation, has full leverage over expected inflation, which further enhances the committed type's incentive to employ a disinflationary policy at startup. As a result, the optimal policy in the case of $\rho_0 = 0.75$ closely resembles the full reputation solution: there is positive but declining inflation, with an initial interval of real stimulus. The optimal policy thus takes the form of "gradualism," which is indeed an alternative disinflation strategy endorsed by many economists, including monetarists such as Friedman, Brunner, and Meltzer.

However, when the initial reputation is weaker, imperfect credibility does have an impact on the optimal policy through the level effect $(1 - \rho)\mu$. This level effect makes the optimal policy more accommodative in the initial period and makes the output costs of disinflation more severe. In real terms, full leverage over inflation expectations yields a stimulative credible disinflation effect, and the level effect of imperfect credibility has a contractionary

non-credible disinflation effect during the early stages of the disinflation path. These are the two elements described by Ball (1994, 1995) and stressed by Goodfriend and King (2005) in their analysis of Volcker disinflation. For our low levels of initial reputation ($\rho_0 = .25$ and $.5$), the two effects cause a boom in the initial period, but the economy subsequently displays declining inflation and an intensifying recession.

Note that learning is much slower in the case of $\rho_0 = 0.25$, when the alternative type mimics the committed policy actions, than when it adopts a fixed action in the benchmark case. It then takes the economy longer to converge to its steady state; hence, there are more periods of output loss. Mimicking by the alternative type is thus a double-edged sword. On the one hand, it endows the committed type with better control over inflation expectations, as its leverage is greater. On the other hand, mimicking may slow learning, which harms the committed type, as it faces a worsened level effect in the inflation-output trade-off.

4 Impulse responses

It is now a common practice for central banks to adopt "inflation targeting", either explicitly or implicitly. It is also common for a central bank to miss the midpoint of the target range by small or large amounts. Thus, how should a central bank respond to a missed inflation target? Should it let the deviation be a bygone, or should it reverse it? The first part of this section addresses this question by studying the optimal response to a one-time implementation error in our model.

Another classic question in the NK literature and in practical policy analysis concerns how a central bank should respond to energy price shocks. In the context of our model, we can interpret the cost-push shock ς_t to the Phillips curve as such a shock. In the second part of this section, we examine the consequence of a persistent cost-push shock, ς_t , for different levels of credibility.

All of the results in this section are to be interpreted as impulse responses in the sense

that they represent deviations from the transitional dynamics shown in the previous section.

4.1 One-time implementation error

We start with the effect of a one-time implementation error, ε_t , at date $t = 0$ with a magnitude of one percent annually (0.25% quarterly). Figure 4.1 plots the impulse responses under full reputation and under zero reputation. As with the transitional dynamics, we need not distinguish model variations because without a change in reputation, the dynamics are the same for all variations.²³ Several observations follow.

First, the implementation error occurs after the policy action a_t , so there is no initial period response in policy (panel A).

Second, the positive one-time unexpected implementation error ε_t increases output if expected inflation is held fixed, according to the Phillips curve:

$$\pi_t = a_t + \varepsilon_t = \beta E_t \pi_{t+1} + \kappa x_t + \zeta_t.$$

With full reputation, since the policy action is taken before the implementation error, the only control that the committed monetary authority has over the response of current output to the implementation shock is via inflation expectations. Thus, the optimizing committed monetary authority chooses to have expected inflation increase to partially mitigate the impact effect on output and, in effect, to smooth the shock's effect by raising output and inflation in subsequent periods.²⁴ As a result, unexpectedly high inflation arising from an implementation error is optimally followed by an interval of higher-than-average inflation, resembling the start-up dynamics.

Third, by contrast, with zero reputation, the monetary authority has no influence over

²³Note that the response under zero reputation does not apply to the tagalong alternative type's case.

²⁴In fact, Appendix B shows that the monetary authority's current policy response to the past implementation error is governed by the same coefficient as the persistence in policy actions in the transitional dynamics because the responses to past monetary actions and to past monetary policy errors both reflect the monetary authority's desire to manage the response of expected inflation to actual inflation.

expectations, and thus, its future behavior does not respond to this one-time implementation shock. Hence, the date $t = 0$ output effect is maximized, and there is no persistence in inflation or real activity.

We now turn to cases with $0 < \rho_0 < 1$. Figure 4.2 compares the impulse responses under different levels of initial reputation in three model variations.

4.1.1 Constant credibility

The equivalence between startup and implementation error responses in the full reputation case carries over to situations with alternative constant levels of credibility, although the strength diminishes in ρ . As in the discussion of transitional dynamics, the weakened response – less persistent startup disinflation and a less persistent policy response to implementation shocks – reflects the fact that the policymaker sees only part of expected inflation responding to its policy actions. Suppose an implementation error occurred in the previous period, i.e., $\pi_{t-1} = a_{t-1} + \varepsilon_{t-1}$. The policymaker faces inflation expectations $E_{t-1}\pi_t = \rho E a_t^{\tau=1} | (\pi_{t-1}, s_t) + (1 - \rho)\mu$ and cannot as effectively manage these expectations to offset ε_{t-1} when $\rho < 1$. As a result, with reduced credibility, the real effect is larger on impact and is less smoothed out over time.

4.1.2 Benchmark alternative type

We see that an optimal policy response allows expected inflation to rise in period 0 by increasing $a^{\tau=1}$ at date 1, so that the output effect of the implementation error is muted on impact, as in the full reputation case. As in the constant credibility case, imperfect credibility limits the policymaker’s ability to manage inflation expectations, so that the policy response to the implementation error is weaker if the initial reputation is weaker.

However, new elements emerge when the private sector is learning. A positive implementation error causes realized inflation to be unexpectedly higher than the committed type’s inflation action, which, under Bayes’ rule (9), results in a downward revision of the private

sector's probability assessment that the monetary authority is the committed type. The deterioration in reputation moves expected inflation in period 0 against the interests of the monetary authority, reducing the initial output gain relative to the gain in the constant credibility case. Because the drop in ρ is larger for a monetary authority with a weaker initial reputation, as reflected in Panel C of the benchmark case in Figure 4.2, the effect on the initial output is stronger.

The deterioration in reputation caused by the one-time implementation error also implies that reputation must be rebuilt in the future. In Panel A of the benchmark case in Figure 4.2, there is a protracted period of negative inflation actions following the initial policy accommodation to the implementation error. The committed monetary authority implements these negative inflation rates to better distinguish itself from the alternative type. These tougher policy actions have adverse output effects. Unlike in the constant credibility case, in which a one-time implementation error generates a boom at all levels of credibility, the optimal policy response that takes into account its effect on private sector's learning always generates a recession after the initial stimulus. With a weaker initial reputation, the committed monetary authority implements the deflationary policy more aggressively to recover from the larger loss in reputation caused by the implementation error. Consequently, the cost of reputation building in real terms is greater.

4.1.3 Tag-along alternative type

As in the previous case, the implementation error causes a decline in ρ_1 when the private sector is learning. However, the tag-along behavior of the alternative type in this case suppresses the effect of policy on learning. The optimal policy is thus merely responding to the reputation dynamics, which are determined exogenously by the implementation error shock, the inflation premium μ and the initial reputation ρ_0 . Panel C of the tag-along case in Figure 4.2 shows that the negative impact of the implementation error on reputation is stronger and more persistent when the initial reputation is weaker.

Knowing that the alternative type will mimic its inflation action, the committed type has full leverage over expectations despite its imperfect credibility. The deteriorated reputation thus only matters to the level effect of imperfect credibility on the trade-off between inflation and output. Recall that the level effect is determined by $(1 - \rho)\mu$, so that a loss in reputation will increase the expected inflation rate by $|\Delta\rho|\mu$. According to our analysis in section 3, the committed type disinflates more aggressively when faced with a weaker initial reputation because it requires a larger decrease in inflation to offset the adverse effect of higher expected inflation on output. In the transitional dynamics, the more aggressive disinflation is reflected by a more accommodative initial inflation, as shown in Panel A of Figure 3.5. However, in the response to the one-time implementation error, the policy accommodation in period 1 is nearly identical across different initial reputation conditions because the decline in ρ_1 increases the expected inflation rate in period 0 and limits the scope for increasing $a^{\tau=1}$ at date 1 if the committed type wishes to maintain the output boom of the initial period.

Relative to its impact in the endogenous credibility case with a benchmark alternative, the negative impact of the implementation error on reputation is much more persistent with $\rho_0 = 0.25$ and 0.5 when the policy has no effect on private sector's learning. Let us consider the case of $\rho_0 = 0.25$ as an example. In Panel C of the benchmark case, the negative effect on reputation nearly disappears at date 6, whereas in Panel C of the tag-along case, at least half of the negative impact remains at date 6. Therefore, the output loss due to the deterioration in reputation is more back-loaded under a tag-along alternative type, and real activity converges to the steady state at a much slower pace.

4.2 Persistent cost-push shock

We now turn to the effect of a cost-push shock, ς_t , at date 0 with a magnitude of one percent annually (0.25% quarterly) and persistence 0.9.

Figure 4.3 plots the impulse responses under full reputation and zero reputation, which correspond to the full commitment solution and the full discretion solution in the literature.

This cost-push shock has a contractionary effect in both cases. Under full commitment, optimal policy is a form of "flexible price level targeting".²⁵ Therefore, the response of inflation action when $\rho = 1$ is first positive and then negative. Without commitment, Clarida, Gali, and Gertler (1999) show that the optimal inflation policy depends only on ς_t as the policymaker has no control over expectations. Hence, the path of inflation actions when $\rho = 0$ reflects the persistence of the shock.

The fact that optimal policy under full commitment responds to the lagged cost-push shock stems from the ability of the monetary authority to reduce expected inflation. The reduction in expected inflation provides the monetary authority an additional channel through which to offset the effect of a cost-push shock ς and in turn, to better stabilize inflation and output. To demonstrate how imperfect credibility and different views of the alternative type's behavior affect policy responses to the cost-push shock, Figure 4.4 compares impulse responses in three model variations,²⁶ each based on a particular initial reputation $\rho_0 \in \{0.25, 0.5, 0.75\}$.

4.2.1 Constant credibility

Unlike in the full reputation case, when ρ is fixed at an intermediate value, the monetary authority only has partial leverage over inflation expectations, which weakens its ability to smooth the effect of the cost-push shock. Hence, the responses of optimal policy and output lie between their counterparts in the full reputation and zero reputation cases. In particular, optimal policy shifts from "flexible price level targeting" to "flexible inflation level targeting." The optimal output response is more front-loaded when the level of ρ is lower.

²⁵Table B.2 of Appendix B shows that when $\rho = 1$, the coefficients of the policy response to the current and lagged cost-push shock are equal in absolute value and are of opposite signs so that there is no long-term effect of these shocks on the price level.

²⁶Impulse responses are displayed by 'pentagrams' in the constant credibility model, by 'squares' in the benchmark alternative model, and by 'hexagrams' in the tag-along alternative model.

4.2.2 Benchmark alternative type

When reputation is endogenous, the cost-push shock provides a good opportunity for the committed monetary authority to invest in reputation, as the alternative type responds to the cost-push shock with a coefficient (ϕ) equal to 1.98, which effectively adds 2% annual inflation to the 4% inflation bias. As a result, the inflation actions taken by the committed monetary authority are less accommodative to the cost-push shock than are the actions taken in the constant credibility case, in which learning is not relevant. The gain in reputation is shown in Panel C in Figure 4.4 and is particularly pronounced in the case of a weaker initial reputation ($\rho_0 = 0.25$). Due to reputation building, the output loss caused by the cost-push shock is mitigated in all periods and under all initial reputation conditions, relative to the case of constant credibility.

4.2.3 Tag-along alternative type

When the alternative type displays mimicking behavior, it gives the committed monetary authority full leverage over expectations. With inflation expectations more firmly anchored, the committed monetary authority can afford to be less accommodating in its policy response to the cost-push shock while still keeping the output loss smaller than in the constant credibility case.

Given a tag-along alternative type, the committed type cannot affect private sector's learning through its policies. However, its policies do respond to its evolving reputation, which is a by-product of the cost-push shock as the shock enlarges the inflation premium of the alternative type ($\mu + \phi\varsigma_t$) and, in turn, speeds up private sector's learning, according to Bayes' rule (9).²⁷ With the current realization of the cost-push shock, Panel C shows that the gain in reputation is larger when the initial reputation is weaker. Improvement in reputation alleviates the level effect of imperfect credibility on the inflation-output trade-off.

Recall that in our previous experiments, the level effect drives the committed type with

²⁷Both μ and ϕ are set equal to their values in the benchmark alternative case.

a weaker initial reputation to disinflate more aggressively. Therefore, when the initial reputation is weak ($\rho_0 = 0.25$) and the gain in reputation is large, we see a large upward revision of policy in response to the positive and persistent cost-push shock.

4.2.4 Weaker vs. stronger initial reputation

It is noticeable that the policy responses across three model variations differ significantly when the initial reputation is weak ($\rho_0 = 0.25$), whereas they are much more similar to each other when the initial reputation is strong ($\rho_0 = 0.5$ and 0.75). This is because the effect of the cost-push shock on reputation varies across models and initial reputation. When the initial reputation is strong ($\rho_0 = 0.75$), the gain in reputation is quite small when the private sector is learning, which makes the policy response more similar to the response in the constant credibility case. A much larger gain in reputation occurs when the initial reputation is weak ($\rho_0 = 0.25$), and this gain affects the committed type's policy differently depending on whether the alternative type displays mimicking behavior. In the case of a tag-along alternative, the committed policy has no effect on private sector's learning; it therefore responds dramatically to the rise in reputation. In the case of a benchmark alternative, the committed policy also responds to the change in reputation but does so in a much more limited fashion, as a more accommodating policy in this case will retard learning and, in turn, will erode the gain in reputation brought by the cost-push shock.

Turn to the real effect of the cost-push shock. Although output drops in all cases and in nearly all periods, it drops less when improvement in reputation is more significant.

5 Interest rates and interest rate targets

We now investigate the construction of an interest rate target that is consistent with the inflation target $a^{\tau=1}$. Toward this end, we use conventional loglinear approximations to

compute real and nominal yields in keeping with the spirit of the loglinear NK model.²⁸ Given the nature of the timeline discussed in section 2, we consider two points at which financial markets operate. Working backwards, we first consider asset prices and interest rates in markets that are contemporaneous with macroeconomic outcomes (so that they are conditional on realized inflation π as well as on the initial state of the economy at the start of the period (ρ, η, ς)). Second, we consider markets that are contemporaneous with the policy decision (which just depends on (ρ, η, ς)). We call these markets the end-of-period market and start-of-period market, respectively. We think of the start-of-period market at t as one in which agents can sign futures contracts to deliver goods or assets in the end-of-period market at t .

5.1 Short-term interest rates in the end-of-period market

Consider first one real bond and one nominal bond traded in the end-of-period market at t that promise to pay 1 unit of goods and 1 unit of money, respectively, after the realization of inflation at $t + 1$. These assets will be priced based on realized inflation at t as well as the state variables, so that we find it convenient to define the expectation operator E_t^+ conditional on the end-of-period information set $(\rho_t, \eta_t, \varsigma_t, \pi_t)$. For these one-period bonds, loglinear approximation asset pricing formulae provide the familiar IS and Fisher equations in the NK model,

$$r_{1t} \equiv r_1(\rho_t, \eta_t, \varsigma_t, \pi_t) = -\log(\beta) + \sigma[E_t^+ x_{t+1} - x_t], \quad (17)$$

$$i_{1t} \equiv i_1(\rho_t, \eta_t, \varsigma_t, \pi_t) = r_{1t} + E_t^+ \pi_{t+1}. \quad (18)$$

²⁸In doing so, we abstain from considering potentially interesting interactions between risk premia and shifting beliefs about the monetary authority's type. However, the loglinear approximation highlights another type of time variation in returns. In prior sections, we saw that inflation π and output x were nonlinear functions of the state vector $\rho_t, \eta_t, \varsigma_t$ as well as the implementation error. These nonlinearities can be important to the behavior of interest rates, even when there are no risk premia.

5.2 Short-term interest rates in the start-of-period market

Next consider a futures contract in the start-of-period market at t that agrees to deliver a one-period real or nominal bond at a predetermined price in the end-of-period market at t in all states of inflation. For these assets, loglinear asset pricing formulae provide *ex ante* versions of the familiar IS and Fisher equations in the NK model,

$$R_{1t} \equiv R_1(\rho_t, \eta_t, \varsigma_t) = -\log(\beta) + \sigma[E_t x_{t+1} - x_t], \quad (19)$$

$$I_{1t} \equiv I_1(\rho_t, \eta_t, \varsigma_t) = R_{1t} + E_t \pi_{t+1}. \quad (20)$$

Note that in the two expressions above, the expectation operator E_t differs from E_t^+ as the start-of-period information set does not include realized inflation. Within the loglinear asset pricing framework, $R_{1t} = E_t r_{1t}$ and $I_{1t} = E_t i_{1t}$.

5.3 Short-term interest rate targets

A prominent feature of inflation targeting regimes is the announcement of an interest rate or interest rate path that is consistent with the desired path of inflation. In our setting, the inflation target is $a^{\tau=1}$ for both committed and alternative monetary authorities. As we have seen, there are a variety of interest rates that can be constructed in our framework, so it is natural to inquire about the nature of the consistent interest rate that would be presented in an inflation report.

Imperfect credibility generates tricky issues for an inflation targeting monetary authority. In our view, the most natural interest rate to accompany the inflation target is the forecast of the end-of-period rate, $E_t i_{1t}^{\tau=1} = \int i_1(\rho, \eta, \varsigma, \pi) \delta(\pi | a^{\tau=1}) d\pi$, or the mode of the nominal rate, $i_1(\rho, \eta, \varsigma, a^{\tau=1})$, both of which are conditioned on the monetary authority being of the committed type and are thus internally consistent with the inflation target $a^{\tau=1}$.²⁹ In the US institutional context, either of these measures could involve the location of the band for

²⁹This sort of interest rate forecast targeting is also considered in Giannoni and Woodford (2004).

the Federal Funds rate, whereas $i_1(\rho, \eta, \varsigma, \pi)$ would represent the realized Funds rate.

However, these measures would not be the same as interest rates in start-of-period markets, i.e. $I_1(\rho, \eta, \varsigma)$, calculated from the futures contract. With imperfect credibility, $I_1(\rho, \eta, \varsigma)$ will differ from the monetary authority forecast, as $I_{1t} \approx \rho_t E_t i_{1t}^{\tau=1} + (1 - \rho_t) E_t i_{1t}^{\tau=2}$. In the US institutional context, the Fed Funds futures market deviates from the Federal Funds market itself, although this deviation need not be a sign of imperfect credibility when the Funds rate range is adjusted gradually to underlying economic conditions over time.

5.4 Determinacy and observational equivalence

Optimal policy determines the behavior of the end-of-period interest rate as a function of the state of the economy and inflation shocks, as specified in equation (18):

$$i_1(\rho_t, \eta_t, \varsigma_t, \pi_t).$$

In this expression, $\pi_t^\tau = a^\tau(\rho_t, \eta_t, \varsigma_t) + \varepsilon_t$, so that inflation and the interest rate depend on the type of authority in place.

Stepping back from the details of our timing and action structure, we can establish that an identical pattern of outcomes would occur if each type of monetary authority were to set the end-of-period short-term interest rate according to:

$$i_{1t}^\tau = i_1(\rho_t, \eta_t, \varsigma_t, \pi_t^\tau) + \theta_t^\tau [e_t - e(\rho_t, \eta_t, \varsigma_t, \pi_t^\tau)], \quad (21)$$

where e_t is the expected inflation, $e(\rho_t, \eta_t, \varsigma_t, \pi_t^\tau)$ is the expected inflation function derived as part of the optimal policy, and θ_t^τ governs the response to deviations of expected inflation from its optimal level.³⁰ A sufficient condition for a unique, stable rational expectations equilibrium under these interest rate rules is that the average response (across types) to

³⁰The proof for this result is given in Appendix E and it covers a wide class of equilibrium stochastic processes in the NK model. The proof utilizes the logic described in King (2000) and Cochrane (2011).

out-of-equilibrium movements in expected inflation satisfies

$$\rho_{t+1}\theta_t^{\tau=1} + (1 - \rho_{t+1})\theta_t^{\tau=2} > 1,$$

which is a form of the Taylor principle. Equivalently, the response of the type 1 authority must satisfy

$$\theta_t^{\tau=1} = \frac{\theta - (1 - \rho_{t+1})\theta_t^{\tau=2}}{\rho_{t+1}}$$

for some $\theta > 1$. If a type 2 monetary authority cannot specify how it will respond to out-of-equilibrium behavior of the expected inflation (i.e., $\theta_t^{\tau=2} = 0$), there is a simple reputational equilibrium modification of the Taylor principle with $\theta = \rho_{t+1}\theta_t^{\tau=1} > 1$: less reputable committed monetary authorities must respond more dramatically to out-of-equilibrium movements in expected inflation to assure determinacy.

The outcomes of our model are thus observationally equivalent to the outcomes of a model with the interest rate rule (21). Furthermore, with $\theta > 1$, we may discuss the workings of such an alternative economy with just the function $i_1(\rho_t, \eta_t, \varsigma_t, \pi_t)$ as the interest rate rule, as out-of-equilibrium movements in expected inflation will never arise.

5.5 Interest rate rule interpretation

To a first-order approximation,³¹ the observed behaviors of the interest rates under type 1 and type 2 authorities are given by

$$i_t^{\tau=1} = i_1(\rho_t, \eta_t, \varsigma_t, \pi_t = a_t^{\tau=1}) + \frac{\partial i_1(\rho_t, \eta_t, \varsigma_t, \pi_t)}{\partial \pi_t} \Big|_{\pi_t = a_t^{\tau=1}} * \varepsilon_t, \quad (22)$$

$$i_t^{\tau=2} = i_1(\rho_t, \eta_t, \varsigma_t, \pi_t = a_t^{\tau=1}) + \frac{\partial i_1(\rho_t, \eta_t, \varsigma_t, \pi_t)}{\partial \pi_t} \Big|_{\pi_t = a_t^{\tau=1}} * [\varepsilon_t + a_t^{\tau=2} - a_t^{\tau=1}]. \quad (23)$$

This approximation suggests that an econometrician observing our economy could interpret it as having interest rates governed by a rule with shocks and "regime switches". Under

³¹The approximation is taken around the level of i_1 arising under a type 1 authority.

this interpretation, equation (22) is the type 1 interest rate rule with shocks

$$\nu_t \equiv \frac{\partial i_1(\rho_t, \eta_t, \varsigma_t, \pi_t)}{\partial \pi_t} \Big|_{\pi_t = a_t^{\tau=1}} * \varepsilon_t.$$

Equation (23) contains the same shocks (as a consequence of our linearization) but also involves an intercept shift $\frac{\partial i_1(\rho_t, \eta_t, \varsigma_t, \pi_t)}{\partial \pi_t} \Big|_{\pi_t = a_t^{\tau=1}} * [a_t^{\tau=2} - a_t^{\tau=1}]$, where the size of the shift depends on the gap between the two policy actions. In the case of a benchmark alternative, the term $[a_t^{\tau=2} - a_t^{\tau=1}]$ is time-varying, whereas it is constant in the case of a tag-along alternative.

Accordingly, a time series econometrician studying our economy might interpret agents as learning about the nature of the interest rate policy rule in place, filtering observed interest rate outcomes to determine whether they originated in ε_t or in $\varepsilon_t + [a_t^{\tau=2} - a_t^{\tau=1}]$ rather than working with inflation outcomes. This description is of interest because there are valuable empirical studies concerning macroeconomic outcomes in settings with changes in interest rate rules and learning. Notably, Erceg and Levin (2003) consider the course of Volcker disinflation within a calibrated NK model in which there is an intercept shift in the Taylor rule about which private agents learn only gradually, while Schorfheide (2005) and Bianchi (2012) estimate small-scale NK models and provide interpretations of U.S. history for longer time periods.

The systematic part of such an estimated rule would likely be based on the econometrician's replacement of η_t and ς_t in $i_1(\rho_t, \eta_t, \varsigma_t, a_t^{\tau=1}(\rho_t, \eta_t, \varsigma_t))$ with

$$\begin{aligned} \eta_t &= -\frac{h}{\kappa}(x_{t-1} - x^*), \\ \varsigma_t &= \pi_t - \kappa x_t - \beta E_t^+ \pi_{t+1}. \end{aligned}$$

The former equation derives from the fact that $\eta_t = \gamma_{t-1}$ and that optimization with respect to output in (10) requires the first-order condition $-h(x_t - x^*) - \kappa\gamma_t = 0$. The latter equation arises from the rearrangement of the forward-looking constraint (3). Hence, such

an estimated rule would depend on current inflation and output, expected future inflation, and past output. The Bayesian learning would map ρ into a function of past inflation rates, possibly captured by a time-varying parameter in the estimated interest rate rule.

6 Summary and forward-looking statements

We have studied optimal monetary policy in an imperfect public monitoring framework in which skeptical private agents learn rationally about the nature of the monetary authority and in which the monetary authority chooses its actions, taking private sector's learning into account. A key result was that the optimal pattern of inflation management depended critically on the nature of the skepticism of the private sector, whether it was principally caused by a mechanically inflationary alternative monetary authority (the benchmark alternative) or by one that would mimic the committed monetary authority's actions (the tag-along alternative). This result reinforces our view that an understanding of optimal policy under imperfect credibility requires an analysis of the nature of the strategic interaction between types of policy authorities, a topic that we have begun to examine in companion research.

We have also shown that our theoretical results on optimal inflation targets can be mapped to interest rate rules that are widely used in empirical work on monetary policies. In addition, the framework and the recursive method for computing optimal policy in this paper are flexible enough to accommodate a wide class of behavioral rules followed by the alternative monetary authority. These features make our model empirically relevant since a researcher can solve for the optimal policy using our recursive method with a behavior rule of the alternative type that is consistent with data on private sector's expectations. The optimal policy can be then mapped into an interest rate rule to be tested against the data.

Our focus in this paper has been on issues of imperfect credibility that are plausibly relevant to the 1970s through the early 2000s, in that we examined disinflation dynamics and stabilization policy. However, recent events in advanced economies have generated new

challenges for the world's central banks in terms of both monetary and banking policy. In particular, the difficulty of conducting monetary and banking policy at the zero lower bound and the ongoing challenges to the European monetary system are clearly very different from the problems that confronted central banks in the 1980s. Nevertheless, we view issues of imperfect credibility as central to each of these more recent developments, and thus, these issues also motivate our research on the design of optimal policy in settings that feature private sector skepticism.

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Tables

Parameter	First Equation	Definition	Benchmark
β	(1)	Discount factor	.995
h	(2)	Output weight	.004
x^*	(2)	Output target	.1
κ	(3)	PC output slope	.04
δ	Appendix B	Persistence of cost-push shock	.9
σ_ς	Appendix D	Std of cost-push shock	.02
σ	(9)	Std of implementation error	.01
μ	(4)	inflation bias under discretion	1%
ϕ	(4)	stabilization bias under discretion	1.98

Variable	First Equation	Definition
π	(1)	Inflation
x	(1)	Output gap
u	(1)	Momentary objective
e	Appendix A	Expected inflation
τ	(4)	Type of the monetary authority
ς	(3)	cost-push shock
a^τ	(5)	Type-specific policy action
ε	(5)	Implementation error
ρ	(6)	Credibility
s	(7)	True state of the economy
γ	(10)	Commitment multiplier
η	(10)	Pseudo-state variable
Ω	(10)	Intermediate value function
W	(10)	Value function
m	Appendix A	Short-hand for $E\pi_{t+1} a^{\tau=2}$
F	(13)	cdf for implementation error
b	(6)	Bayesian updating function

Table 2.1

Case	Figure	ω_p	ω_b
benchmark alternative	3.2	0	0
no effect of policy on learning	3.3	0	1
no loss of leverage over expected inflation	3.4	1	0
tag-along alternative	3.5	1	1

Table 3.1

Figures

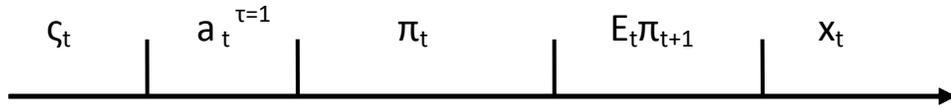


Figure 2.1: Intrapperiod timing

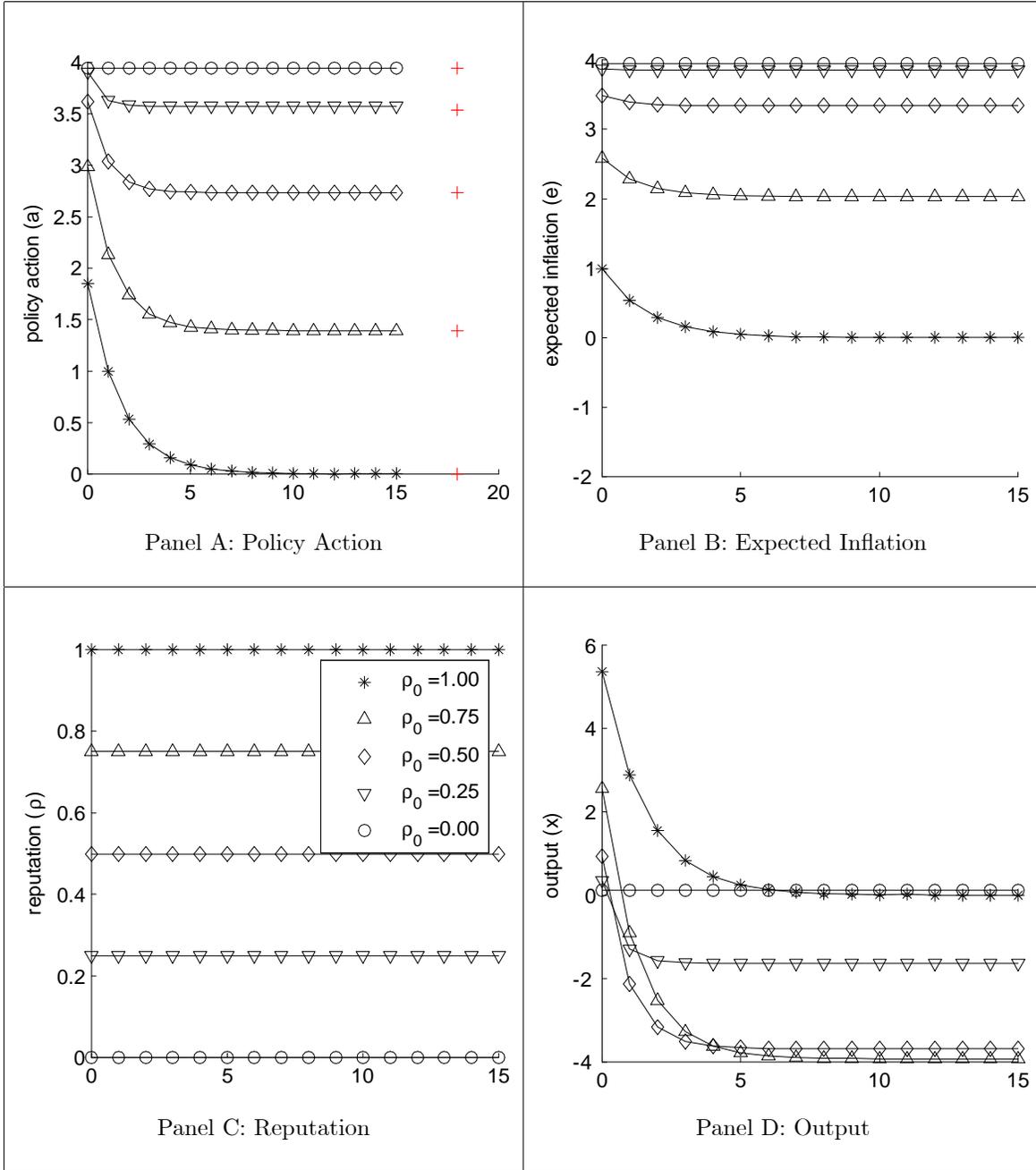


Figure 3.1: Transitional dynamics with a benchmark alternative policymaker and exogenous, constant reputation. Panel A: policy action (mean inflation) is percent per year (the red '+'s indicate the long-run inflation levels computed using the analytical solution in Appendix B). Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

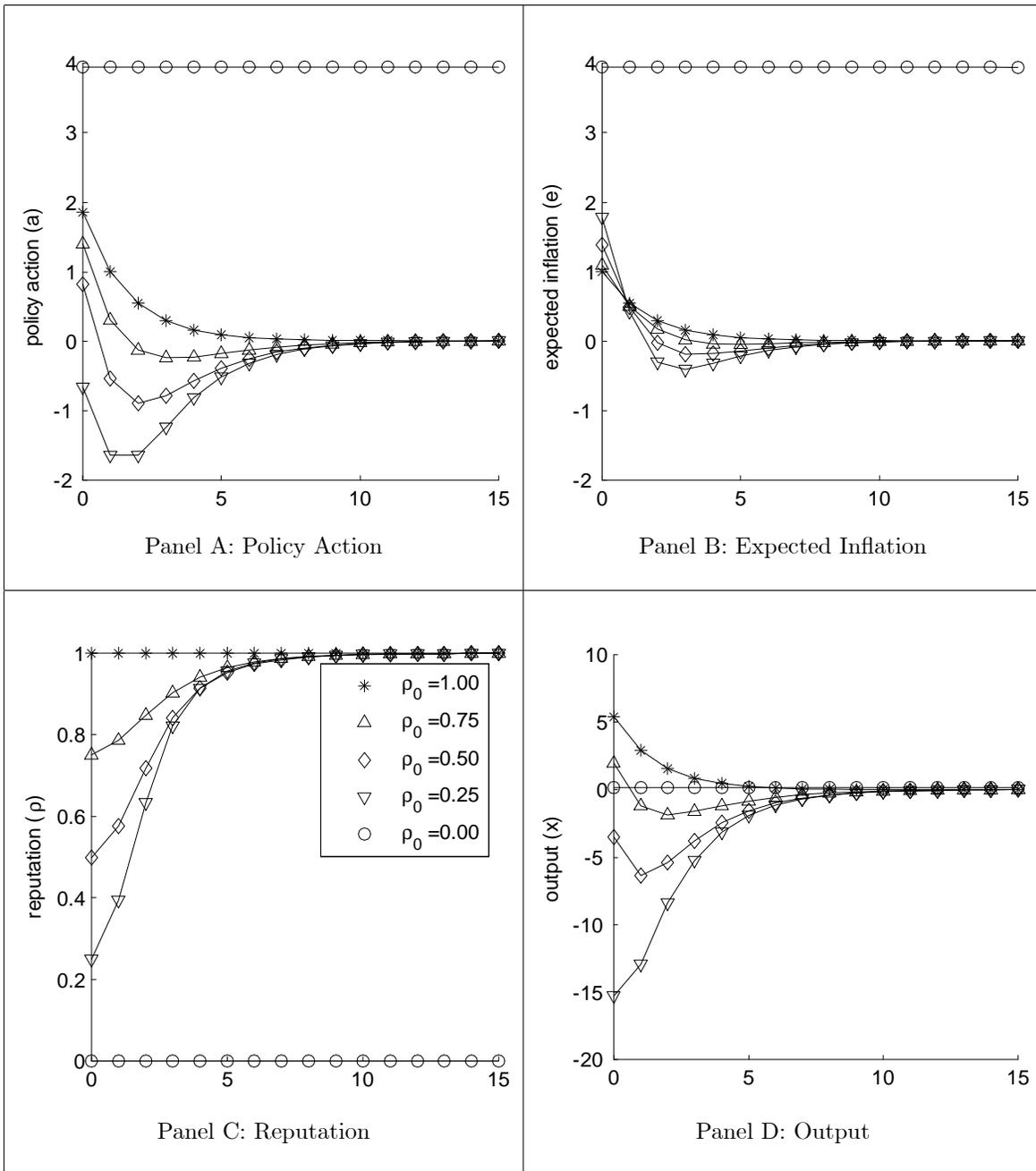


Figure 3.2: Transitional dynamics with a benchmark alternative policymaker and endogenous reputation. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

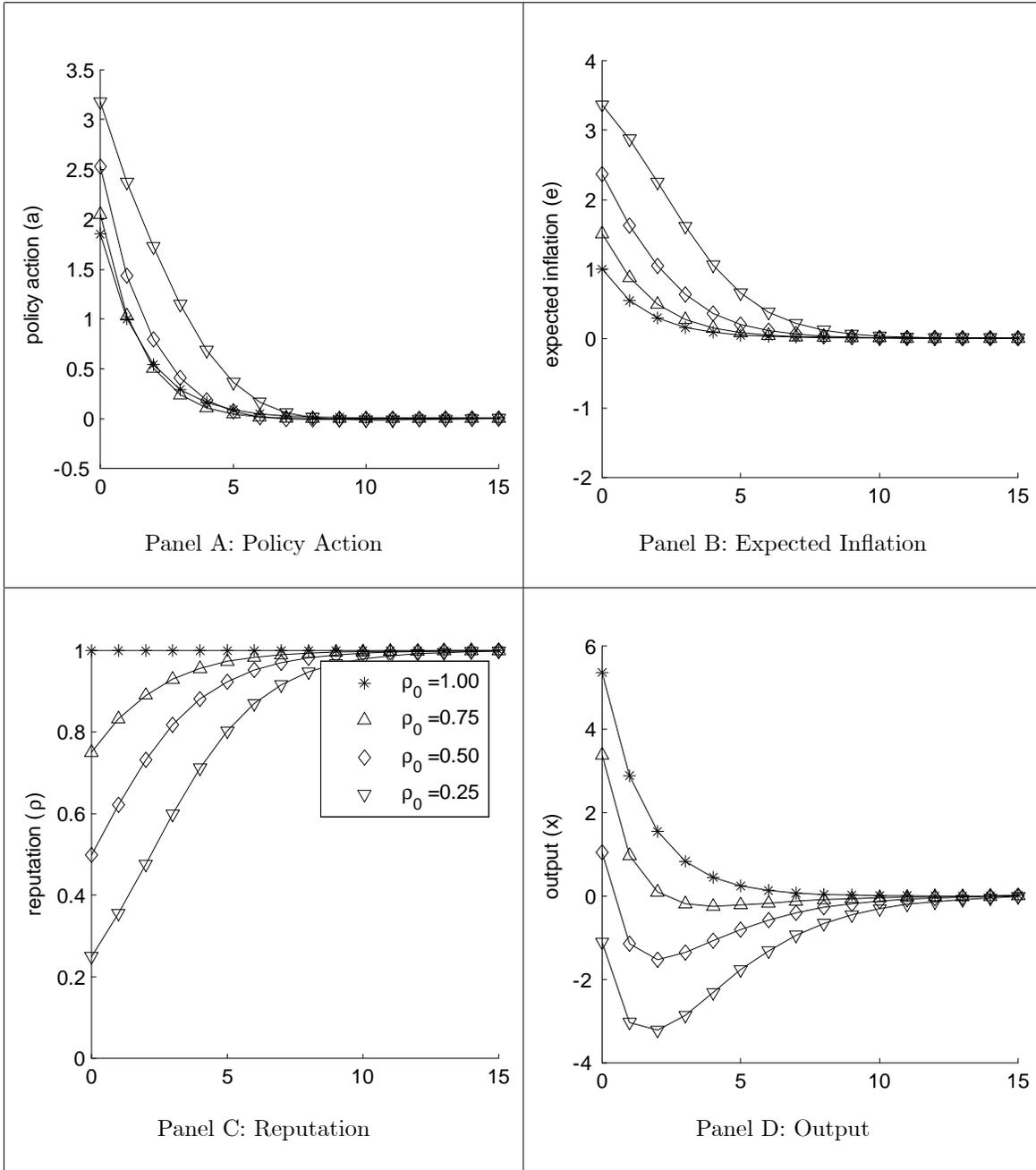


Figure 3.3: Transitional dynamics without effect of policy on learning, but with loss of leverage on expected inflation due to imperfect credibility. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

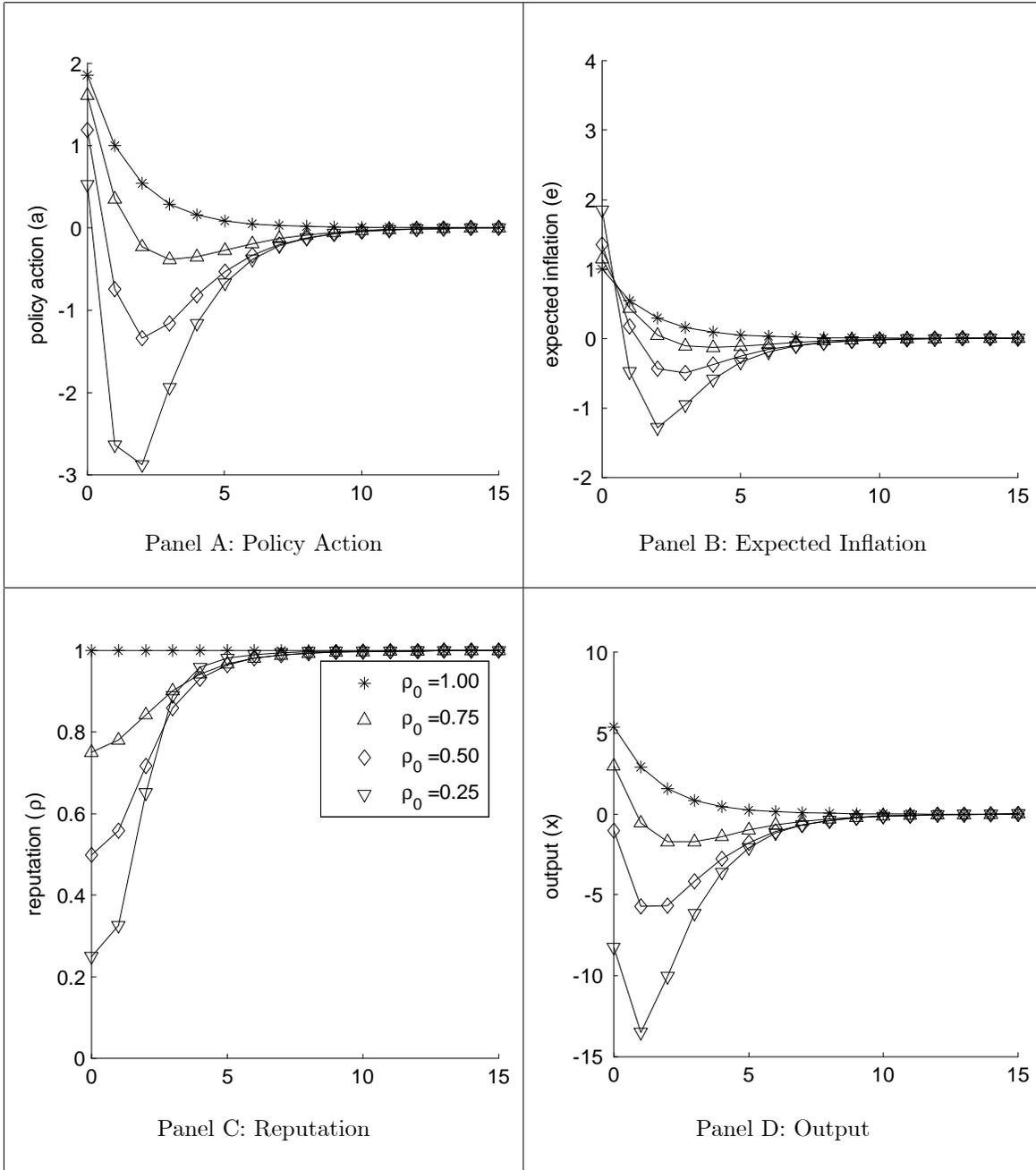


Figure 3.4: Transitional dynamics with effect of policy action on learning, but no loss of leverage on expected inflation. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

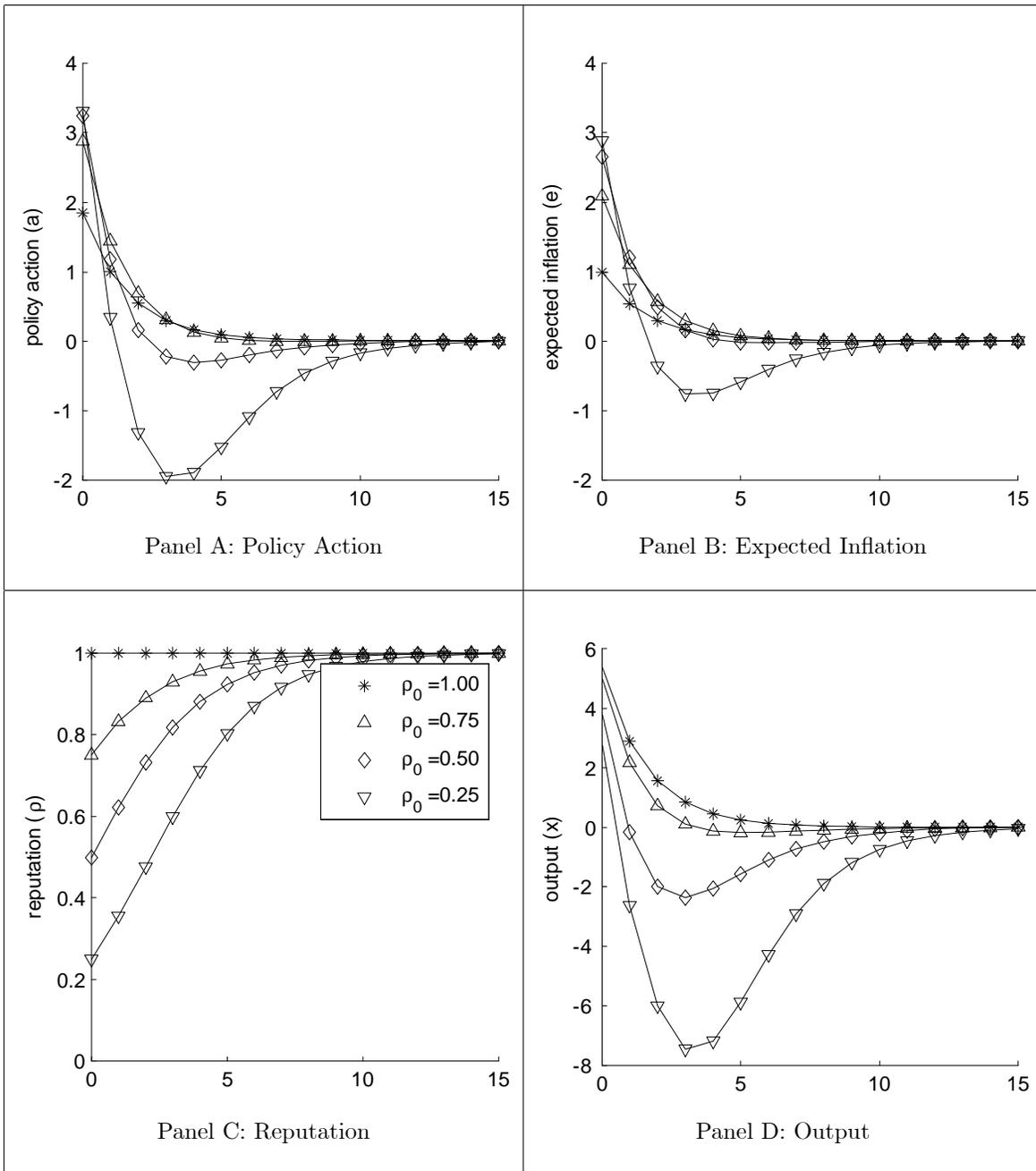


Figure 3.5: Transitional dynamics with a tag-along alternative policymaker and endogenous reputation. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

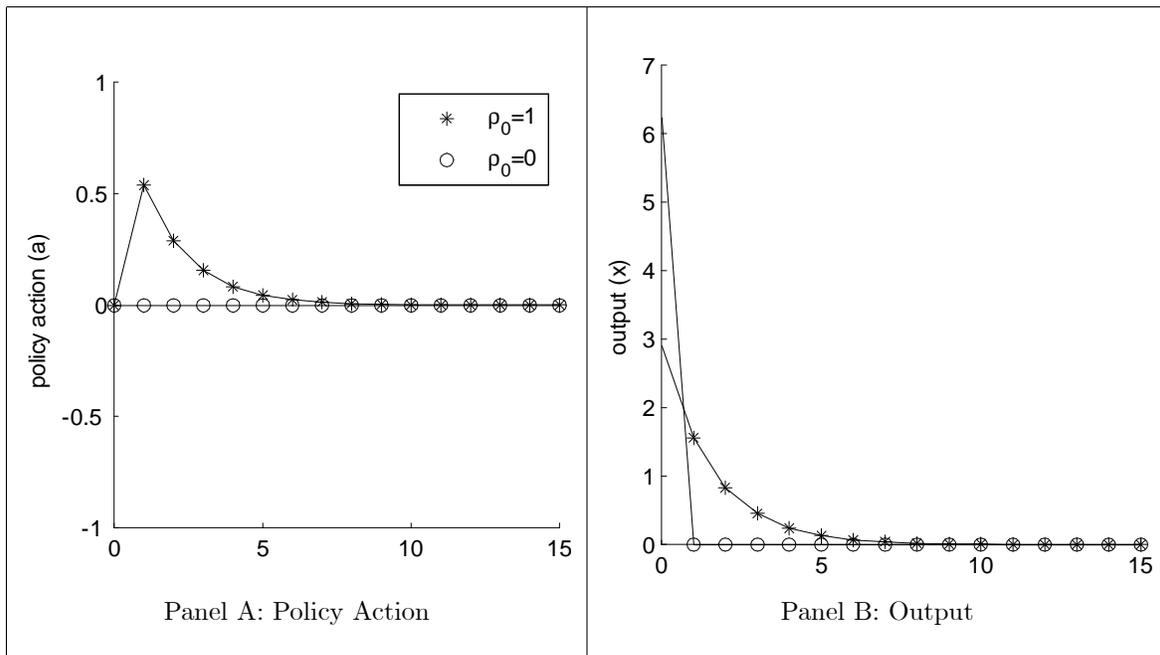


Figure 4.1: Impulse responses to a one-time implementation error (one percent annually) under full reputation and under zero reputation. All variables displayed are deviations from their transitional dynamics. Panel A: policy action (mean inflation) is percent per year. Panel B: output is in percent deviation from distorted steady state.

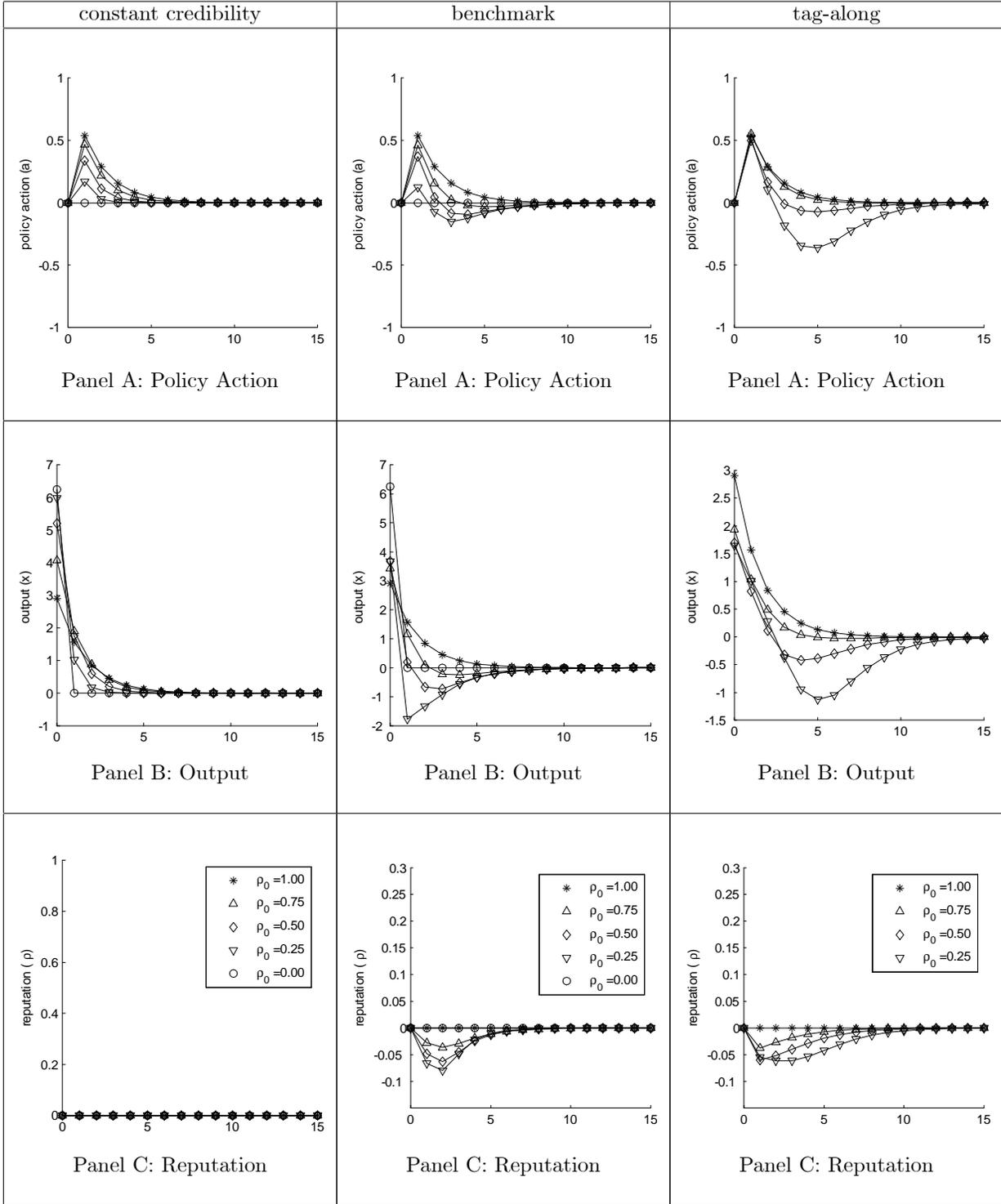


Figure 4.2: Impulse responses to a one-time implementation error (one percent annually) with interior initial reputation conditions in three model variations. All variables displayed are deviations from their transitional dynamics. Panel A: policy action is percent per year. Panel B: output is in percent deviation from distorted steady state. Panel C: reputation is the likelihood that a committed policymaker is in place.

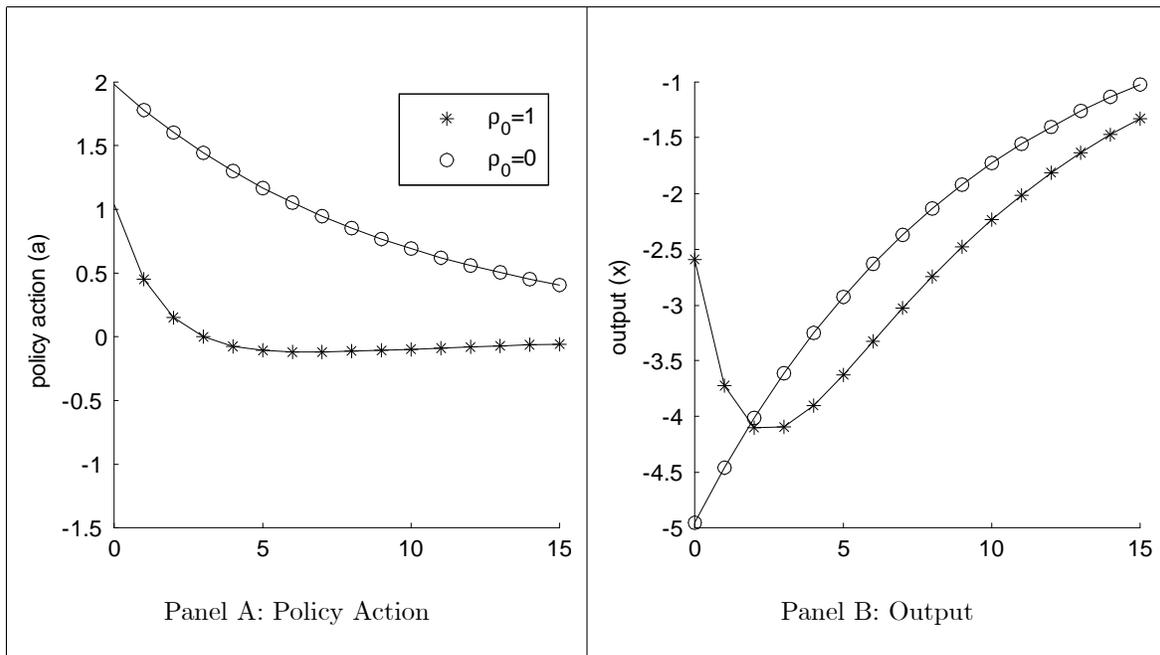


Figure 4.3: Impulse responses to a persistent cost-push shock (one percent annually and persistence .9) under full reputation and under zero reputation. All variables displayed are deviations from their transitional dynamics. Panel A: policy action (mean inflation) is percent per year. Panel B: output is in percent deviation from distorted steady state.

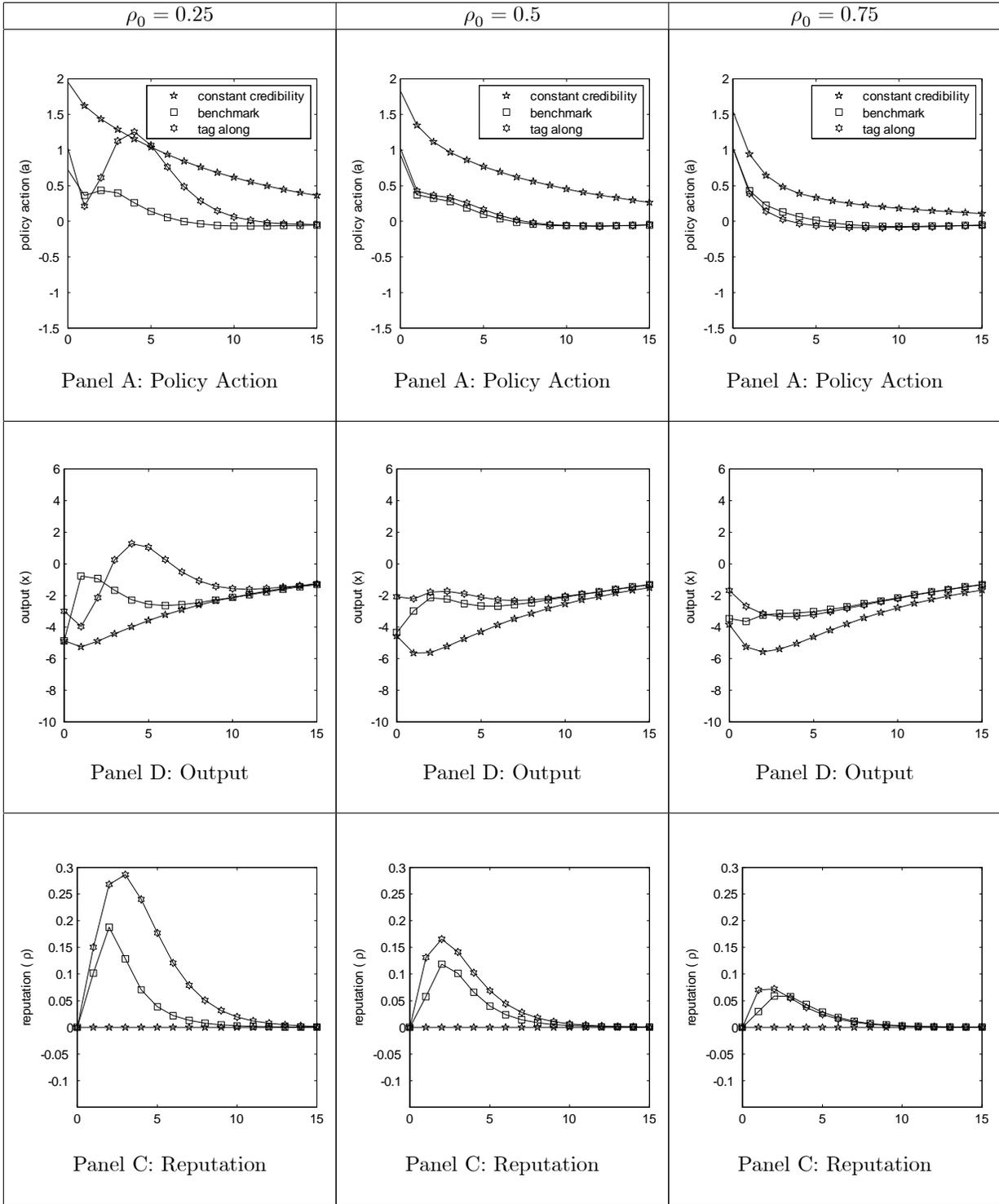


Figure 4.4: Impulse responses to a persistent cost-push shock (one percent annually and persistence .9) in three model variations with interior initial reputation conditions. All variables displayed are deviations from their transitional dynamics. Panel A: policy action is percent per year. Panel B: output is in percent deviation from distorted steady state. Panel C: reputation is the likelihood that a committed policymaker is in place.

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