

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 somewhat skeptical about policy announcements and which interprets economic data as providing evidence about the monetary authority's preferences or its ability to carry through on policy plans? To provide an answer to this question, we extend the standard New Keynesian macroeconomic model to include imperfect inflation control (implementation error relative to an inflation action) and Bayesian learning by private agents about whether the monetary authority is the committed type (capable of following through on announced plans) or an alternative type (producing higher and more volatile inflation). In a benchmark case, we find that optimal policy involves dramatic anti-inflation actions which include an interval of deflation during the early stages of a plan, motivated by investing in a reputation for strength. Such policies resemble recommendations during the 1980s for a "cold turkey" approach to disinflation. However, we also find that such policy is not robustly optimal. A more "gradualist" policy arises if the initial level of credibility is very low. We also investigate a setting where the alternative monetary authority follows a simple behavioral rule that mimics variations in the committed authority's policy action but with a bias toward higher and more volatile inflation. In this case, which we call a "tag along" alternative policymaker, a form of gradualism is always optimal.

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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. The implications of optimal monetary policy for the average level of inflation and the response of inflation to shocks are substantially different under these two assumptions. The commitment solution, in particular, features detailed dynamic plans for the evolution of inflation over time which have a flexible price level targeting interpretation. Since most monetary authorities believe that their policy plans will be carried out, they are led toward some version of the commitment solution as a guide to the design of policy. By contrast, in an equilibrium without commitment, there are alternative simpler rules which give rise to different macroeconomic outcomes, with higher average inflation and permanent variations in the price level.

But how should policy be designed in the middle ground where monetary authorities frequently find themselves, which is that they face a private sector that is somewhat skeptical about policy announcements and which interprets economic data as providing evidence about the monetary authority's preferences or its ability to carry through on policy plans?

In this paper, we provide a reference answer to this question, studying a version of the textbook New Keynesian monetary policy model of linear quadratic form commonly used to simply represent the richer macroeconomic dynamics of medium scale policy models. Within the well-known full commitment case, in which the detailed dynamic policy plan is fully credible, this model has two striking features¹. First, optimal policy involves an initial interval of high, but declining inflation that stimulates real activity, which we term the "start up" phenomenon. Second, optimal policy involves significant accommodation of inflation shocks, so as to offset consequences for real economic activity. A by-product of our work with this model involves showing that these core implications carry over to a setting in which the monetary authority can only imperfectly control inflation due to an implementation error.

To answer the question posed above, it is necessary for us to be specific about the nature of the monetary authority in place and the alternative which the private sector believes may be present. In doing so, we draw a distinction between a committed monetary authority – one that is capable of formulating and carrying out the type of detailed plan derived in a commitment equilibrium – and the extent of its credibility. Our initial focus is on deriving the optimal policy for an authority that can commit but faces a private sector which attaches a probability – an extent of credibility – to that announced policy plan but also believes that policy may be selected according to an alternative plan that is more

¹See, for example, Clarida, Gali, Gertler [1999] and King and Wolman [1999]

inflationary. In terms of the behavior of the alternative monetary authority, our benchmark case is that it follows the simple rule arising in the full information equilibrium without policy commitment, which is well understood to involve both inflation and stabilization biases but no start-up period. When the credibility index is constant over time, we find that optimal policy for the committed monetary authority involves mixture of standard commitment and non-commitment outcomes: there a degree of inflation bias and stabilization bias, in addition to a start-up period of scale diminishing in credibility. This fixed credibility case is a second by product of our work and, like the textbook linear-quadratic model, there is a closed form solution for optimal policy and macroeconomic outcomes.

With this background, we then construct our main environment in which the committed authority formulates an optimal dynamic policy plan but does so recognizing that (i) actual inflation outcomes are more variable than its policy choices due to implementation error; and (ii) private agents learn from inflation outcomes about the nature of the authority that is in place. Under our assumption that the monetary authority has full commitment capability, but that price setters and other private agents are skeptical, we find important departures from standard conclusions about startup inflation and responses to inflation shocks. First, from relatively high levels of credibility (50% and higher), optimal policy features an initial interval of lower inflation than the full commitment solution, with the nature of the path depending on the initial extent of private sector skepticism but frequently involving deflation. Private sector learning is not immediate due to the presence of implementation error, which masks the policy actions of the monetary authority. Essentially, the monetary authority engages in an initial period of *reputation building*.² Second, optimal policy features a time-varying response to inflation shocks. Generally, in our basic model, learning is very fast if initial reputation/credibility is relatively high and so the monetary authority's optimal policies typically approach the standard full commitment solution fairly quickly.³ Hence, with endogenous credibility and from relatively high initial levels of credibility, the short-run is dominated by reputation investment and the long-run looks like the flexible price level targeting solution familiar from the literature.

In the late 1970s and early 1980s, there was much discussion of the appropriate strategy for disinflation in the United States and in other countries. One approach was *gradualism*,

²In the sense of Cripps, Mailath and Samuelson [2004] and Lu [2012]. The precise implications of this reputation investment for optimal policy depend on the structure of the economy, including the learning rule of the private sector, so that there is not a simple, comprehensive prescription such as the use of the "timeless perspective" advocated by Woodford [1999]. Kurozumi [2008] and Loisel [2008] study the issue of whether optimal monetary policy is sustainable in the sense of Chari and Kehoe [1990], using a different notion of reputational equilibria.

³The deflationary interval and the rapid learning are results which are also obtained by Cogley, Matthes and Sbordonne [2011] in substantively related research using a different computational approach.

by which policy reduced the inflation rate slowly with the objective of producing small real losses. Another was to undertake a rapid disinflation, frequently called the *cold turkey* strategy.⁴ A newly reorganized monetary authority with full commitment and credibility in the New Keynesian model would adopt a gradualist policy and there would be a resulting boom in real economic activity.⁵ By contrast, with endogenous credibility and starting from relatively high levels, our reference analysis shows that a rapid disinflation is optimal and that there is a recession, whose depth and duration is larger when initial credibility is lower. Further, our reference analysis shows that policy responds aggressively to avoid deterioration of credibility in the face of implementation errors and other price shocks, with the intensity again depending on the level of credibility. However, if we consider a monetary authority which starts with a relatively low level of credibility (25%), then the cold turkey strategy is not optimal. Instead, the authority behaves in a gradualist manner, reducing inflation while balancing the real costs of disinflation with the gains from investing in reputation. Even though it is gradualist, optimal policy does bring about a deep recession. Further, positive implementation errors – inflation high relative to the optimal action – lead to a more protracted interval of gradual disinflation with higher real costs.

Moreover, an important literature in the 1980s on credible control of inflation stressed that monetary authorities not capable of full commitment (colloquially, weak) might be induced to deliver low and stable inflation by the force of trigger-strategy expectations⁶. In essence, a weak monetary authorities would find it desirable to *mimic* the behavior of a committed monetary authority – specifically, one that was modeled as mechanically a low inflation policy – due to the threat that it would be permanently faced with high inflation expectations and have to repeatedly accommodate these.

As an initial exploration of the potential consequences of such mimicking, we study the nature of optimal policy when the alternative weak monetary authority takes a policy action that adds a "time-varying inflation premium" to the committed central bank's optimal policy action. This *tag-along* behavior is known to the private sector, so that it affects the learning rule facing a committed monetary authority in its optimal policy design. This modification has a dramatic effect on optimal inflation policy: it is gradualist from all levels of initial credibility, although the motivations for the measured pace differ. At a high initial level, the optimal policy closely resembles the commitment solution – learning plays little role – and there is positive but declining inflation with an initial interval of real stimulus. For a low level, the optimal policy also involves an initial interval of high, but declining inflation,

⁴These two strategies are discussed, for example, by Sargent [1982] and Bernanke [2004].

⁵Ball [1994]. Note that this phenomenon extends to our constant partial credibility extension in section 3 below

⁶Sometimes also described as reputation.

but for a very different reason: the monetary authority correctly understands that private sector inflation expectations will be stubborn in response to disinflation events. There is a u-shaped recession in real economic activity.

We use our framework to study several additional issues. First, we explore how evolving credibility leads to a time-varying response of policy and macroeconomic activity to shocks along two dimensions: (i) optimal policy takes into account the interaction of shocks and policy actions as these affect learning; and (ii) the extent of "stabilization bias" is affected by the evolving degree of credibility. Second, we consider how macroeconomic activity would evolve if the alternative authority is in place, motivated both by our interest in understanding the positive implications of the model and our interest in understanding the beliefs that private agents when optimal policy is chosen by the committed type. Third, we consider the behavior of nominal and real interest rates in the economy, appraising how these depend on time-varying private sector expectations of inflation and real activity. We also explain why our optimal solution would be observationally equivalent to the outcomes of a particular interest rate rule for monetary policy; the type of variables shifts that a time series econometrician would be led to incorporate in an empirical study of such a rule; and provide a more speculative reinterpretation of inflation implementation errors as shocks to an interest rate rule.

The organization of the paper is as follows. In section 2, we describe our variant of the textbook New Keynesian model and lay out the recursive optimal policy problem. In section 3, we study the optimal inflation policy and its implications on other macro variables when a new committed monetary authority without pre-existing commitments just takes office. Section 4 studies the optimal policy response to a missed inflation target and to a persistent inflation shock. Section 5 considers experiments with inflation decision made by the alternative monetary authority. In section 6, we explore the behavior of nominal and real interest rate in our model and alternative interpretations of our equilibrium outcomes. Finally, section 7 concludes and provides an overview of planned future work.

2 The Model

2.1 The standard NK problem

A standard New Keynesian optimal policy problem involves a monetary authority maximizing an expected present discounted value objective such as

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

defined over inflation π and output x (relative to an efficient level x^*). Typically, the momentary objective is assumed to be quadratic, as in

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

with $h > 0$. Output is a good and inflation is a 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.⁷

We present the elements of this familiar model in a relatively terse manner, so that Table 2.1 provides the reader with a list of notation and definitions.

2.2 The modifications

Relative to the literature, we introduce several complications to this basic model.

2.2.1 Types of policymakers

We study the design of optimal policy by an authority that is capable of commitment and trustworthy in its messages concerning its inflation plans, which we call the *committed type* ($\tau = 1$) for short. The committed type makes an optimal choice on its inflation plans in period zero and commits to the plans in all subsequent periods. $a^{\tau=1}$ is used to denote the committed type's inflation actions in all periods that are specified by the predetermined state-contingent optimal plans.⁸

⁷Note that these specification have four properties that are central to understanding the dynamic behavior of optimal policy. First, as stressed by Ball [1994], a perfectly credible anticipated disinflation raises 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)). The combination of these two properties means that 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], an 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 an 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

⁸There is a difference between plans and actions since a plan is a mapping from history to a particular action. Therefore, the same plan may result in different paths of actions, depending on the realizations of shocks.

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, in line with the literature on equilibrium policy without commitment, we use a simple *benchmark alternative* specification that can capture inflation and stabilization bias⁹

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

Second, we use a *tagalong alternative* which takes the form

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

This tagalong alternative is meant to capture elements of the strategic mimicking behavior highlighted in the 1980s literature on this topic.

Both of these specifications can be expressed using the general form $a_t^{\tau=2} = \omega a_t^{\tau=1} + \mu + \phi\varsigma_t$, with $\omega = 0$ corresponding to the benchmark alternative type and $\omega = 1$ the tagalong alternative type.

2.2.2 Intra-period timing

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

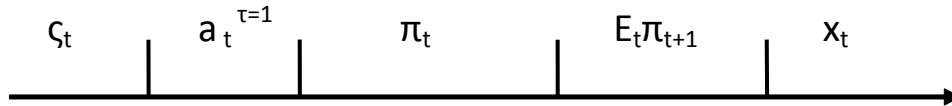


Figure 2.1: Intraperiod timing

⁹As employed in the literature (see, e.g., Galí and Gertler [2007]), inflation bias refers to the higher average inflation rate which arises when policy is determined without commitment capability, while stabilization bias refers to the greater extent of variability of inflation in response to shocks such as ς .

2.2.3 Policy announcement

Although it is not the main focus of this paper, it is useful to make a few comments about the role of the policy announcement made by the monetary authority at the start of each period.¹⁰ If the current monetary authority is the committed type, it will announce its planned action $a_t^{\tau=1}$ which was already chosen at period zero since the plan is ex-ante optimal and the committed type, by definition, has committed to that plan. If the current monetary authority is the alternative type, the current paper assumes 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 modelled signalling game in which both the committed type and the alternative type are strategic message senders and the private sector learns from the policy announcement about sender's type. A detailed study about the signalling equilibrium is beyond the scope of the current paper (since the alternative type is not strategic in our model) but Lu [2012] establishes such an equivalence result in a setup with a strategic alternative type.

2.2.4 Imperfect monitoring

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

$$\pi_t = a_t^\tau + \varepsilon_t \quad (4)$$

where ε_t is an implementation error with a zero mean random variable and a finite variance.¹¹ The action a depends on the type of the monetary authority, τ , but the distribution of the implementation error does not.

In this way, the realized inflation is a noisy signal about the implemented policy action and a deviation of inflation from the policy action does not immediately reveal the identity of the policymaker. We make this modelling choice for two reasons. One is that we think it reflects some realism in monetary policymaking since actual monetary authorities do not always have perfect control over the policy outcome due to unexpected shocks. The other reason is that having the imperfect monitoring allows for more flexibility in modelling dynamics as it avoids a discrete shift in beliefs if the actual policy action deviates from the planned one.

¹⁰The timing of announcements is not important in our model. Put alternatively, if we consider the outcomes determined by our programming problem, then these can be "supported" by a date 0 announcement of $\{a^{\tau=1}(s_t)\}_{t=0}^\infty$ or by a sequence of announcements: $a^{\tau=1}(s_t)$, where s_t is the state of the economy at period t . This is a standard sort of indeterminacy.

¹¹A similar structure with implementation error can be found in Atkeson and Kehoe(2006), Cukierman and Meltzer (1986), etc.

2.2.5 Reputation and credibility

Through the paper, we view private agents as forming expected inflation 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 probability that the monetary authority is of type 1. We use ρ to denote this probability and refer it as the reputation of the monetary authority. We assume that there is Bayesian learning about the monetary authority's type. When the current inflation rate is observed, the private sector's probability ρ_t (as of the start of period t) that the monetary authority is of type 1 is updated according to a Bayesian learning specification

$$\rho_{t+1} = b(\pi_t, \rho_t; a_t^{\tau=1}, a_t^{\tau=2}) \quad (5)$$

where the conventional form of the Bayesian updating function b will be detailed below.

This probability also measures the credibility of the committed monetary authority's plans since it determines the extent to which the policy plans can affect the expected inflation:¹²

$$E_t \pi_{t+1} = \rho_{t+1} E_t [\pi_{t+1} | a^{\tau=1}(s_{t+1})] + (1 - \rho_{t+1}) E_t [\pi_{t+1} | a^{\tau=2}(s_{t+1})] \quad (6)$$

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 at period zero, which 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 $a^{\tau=2}$, which also can depend on the future state of the economy s_{t+1} .¹³ From the perspective of private agents, the former event occurs with probability ρ_{t+1} since they form expectations after observing the 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 expected inflation is:

¹²Generally, we think of the credibility of an inflation plan a^1 as the likelihood that it will be executed, while we think of reputation as the likelihood that an agent is of a particular type (the committed type in the current context). In the present model, credibility of the inflation plan and reputation for commitment are identical. In other settings – notably those with mimicking by the alternative type as in King, Lu and Pasten [2008] and Lu [2012] – credibility of the inflation plan is higher than the reputation state variable.

¹³The behavioral specification is a special case of the one that would arise when we endogenize the strategy of the alternative type, as we are presently undertaking based on the the approach developed in KLP [2011].

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

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 there is zero expected implementation error, 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* on expectations. Note also that a part 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: this exogenous component is larger if policy is less credible (lower ρ) and if the autonomous component of near-term expected inflation is larger.

2.3 Interaction of credibility and policy

We will see that the extent of policymaker reputation (ρ) will have major implications for the nature of optimal policy undertaken by a committed policymaker. At this stage, it is therefore useful to review the four model components where credibility enters. Doing so, we identify four channels of effect.

2.3.1 Effects of credibility on the trade-off

The inflation specification (3) implies that

$$\pi_t = \kappa x_t + \beta l_{t+1}[E_t a_{t+1}^{\tau=1}] + \beta(1 - \rho_{t+1})[\mu + \phi E_t \varsigma_{t+1}] + \varsigma_t \quad (7)$$

In terms of the trade-off between inflation and output that constrains optimal policy, there is a *level effect* on the trade-off $\beta(1 - \rho_{t+1})[\mu + \phi E_t \varsigma_{t+1}]$, and a *slope effect*, $\beta l_{t+1}[E_t a_{t+1}^{\tau=1}]$, with $l_{t+1} = \rho_{t+1} + \omega(1 - \rho_{t+1})$. Each of these influences the consequences of the current policy action $a_t^{\tau=1}$ or the future policy actions such as $a_{t+1}^{\tau=1}$. Generally, higher credibility reduces the level effect and raises the slope effect. With a benchmark alternative policymaker ($\omega = 0$), credibility variable is evidently relevant for 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 $l_{t+1} = 1$ always.

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 directly has a *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 it, notice that with an assumption that the implementation error is normally distributed: $\psi(\pi; a) = \frac{1}{\sigma} \exp(-\frac{(\pi-a)^2}{2\sigma^2})$.¹⁴, the learning specification can be written as

$$\begin{aligned} b(\pi_t, \rho_t; a_t^{\tau=1}, a_t^{\tau=2}) &= \frac{\rho_t}{\rho_t + (1 - \rho_t) \exp(\frac{[(\pi_t - a_t^{\tau=1})^2 - (\pi_t - a_t^{\tau=2})^2]}{2\sigma^2})} \\ &= \frac{\rho_t}{\rho_t + (1 - \rho_t) \exp(\frac{[-2\varepsilon_t(a_t^{\tau=1} - a_t^{\tau=2}) + (a_t^{\tau=1} - a_t^{\tau=2})^2]}{-2\sigma^2})} \text{ if } \pi_t = a_t^{\tau=1} + \varepsilon_t \end{aligned} \quad (8)$$

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 – at a given implementation error – and raise ρ_{t+1} . However, under our tagalong assumption ($\omega = 1$ implies $a^{\tau=2} - a^{\tau=1} = \mu + \phi\varsigma$), 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 multiple, say γ_t , to the forward-looking constraint (3), to then find the first order conditions, and to finally determine the optimal behavior of the 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 of Khan, King and Wolman [2003] on optimal monetary policy. Since 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.

¹⁴We drop the factor $(2\pi)^{-1}$ in the normal pdf from the front of ϕ to avoid confusion with the inflation rate.

Define the *interim value function* Ω via

$$\begin{aligned}\Omega(\rho_t, \eta_t, \varsigma_t, a_t^{\tau=1}, \pi_t) = & \min_{\gamma_t} \max_{x_t} \{u(\pi_t, x_t) \\ & + \gamma_t[\pi_t - \kappa x_t - \varsigma_t] - \eta_t(l_t \pi_t + (1 - \rho_t)[\mu + \phi \varsigma_t]) \\ & + \beta EW(\rho_{t+1}, \eta_{t+1}, \varsigma_{t+1}) | \rho_t, \eta_t, \varsigma_t, a_t^{\tau=1}, \pi_t\}\end{aligned}\quad (9)$$

with

$$\eta_{t+1} = \gamma_t. \quad (10)$$

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

$$\rho_{t+1} = b(\pi_t, \rho_t; a_t^{\tau=1}, a_t^{\tau=2}) \quad (11)$$

being required by (5). Also define the *initial value function* W as

$$W(\rho_t, \eta_t, \varsigma_t) = \max_{a_t^{\tau=1}} \int \Omega(\rho_t, \eta_t, \varsigma_t, a_t^{\tau=1}, \pi_t) dF(\pi_t | a_t^{\tau=1}) \quad (12)$$

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

We establish the appropriateness of this recursive system in King and Lu (2011) – Appendix A briefly summarizes the derivations for our restricted setup – so that we focus here on its economic content. The policy action,

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

must be made by the monetary authority without exact knowledge of its ultimate consequences for inflation so that the form of (12) 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 there will be consequences of its future actions for how expected inflation responds to the actual inflation outcome. In turn, the expectations response governs how output responds to inflation given the forward-looking constraint (3). This is why the recursive policy problem for the monetary authority also involves the optimization in (9), with the outcome being a pair of *contingency plans* for output

$$x(\rho_t, \eta_t, \varsigma_t, \pi_t) = x(\rho_t, \eta_t, \varsigma_t, a^{\tau=1}(\rho_t, \eta_t, \varsigma_t), \pi_t) \quad (14)$$

and for the commitment multiplier

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

that is attached to (3).¹⁵ The choice of the commitment multiplier γ is the vehicle by which the recursive representation captures the management of expectations conditional on π_t .¹⁶

3 Transitional dynamics

In this section, we study the inflation policy that would be followed by a new committed monetary authority without the 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, 1.¹⁷ We refer $\rho_0 = 0.5$ as our fifty-fifty case; $\rho_0 = 0.75$ and $\rho_0 = 0.25$ as stronger and weaker initial reputation cases, respectively. Panel A of 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 structural inflation shocks occur ($\varsigma = 0$). The subsequent panels display expected inflation e (panel B), reputation/credibility ρ (panel C) and real output x (panel D).

As well known, the full commitment solution in the New Keynesian model implies that there should be an initial interval of high, but declining, inflation: this 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 with full commitment.

In this section, we explore three substantive model variations to illustrate how imperfect credibility and different views on the alternative type's behavior change the optimal policies from the standard NK prescriptions. We start with a case where the credibility is exogenous and constant. Then we allow for endogenous credibility and study the impact of private sector's learning on optimal policies. Finally we study the implications of having a tag-along

¹⁵The right-hand side of these expressions gives the contingency plan derived from (9), which is conditional on an arbitrary action a . The left-hand side involves a short-hand expression that embed an evaluation at the evaluates at at its optimal level (13).

¹⁶In 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 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. Put 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 also is consistent with the general framework of Marcet and Marimon [1998, 2011]. As indicated earlier, our generalization to a strategic alternative type in KLP [2011] leads to a number of pseudo-state variables and these are not all governed by a simple lagged multiplier mechanism, so that the notation is better consistent with our research path.

¹⁷Symbol references are 1(*), .75(Δ), .5(◇), .25(▽), 0(○).

alternative type that mimics the committed type’s policy actions.

Across all the model variations, the full reputation ($\rho_0 = 1$) solutions are exactly the same since reputation stays fixed at the level 1 from this initial condition. The solutions under full reputation replicate the basic features of the NK model with full commitment. The zero reputation ($\rho_0 = 0$) solutions are also the same with or without the private sector’s learning so long as the private sector perceives the alternative monetary authority to behave in the same manner. Under the assumption that the alternative type is the benchmark case, 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. Since under these initial conditions (full and nonexistent commitment) 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.¹⁸ The results reported in this case set a benchmark for our endogenous credibility analysis and it also allows a comparison to the work of Schaumburg and Tambalotti [2007], who also study optimal policy in a setting where agents are skeptical about the degree of policymaker commitment. In their analysis, the monetary authority recognizes that it will be replaced with a probability that is also known by private agents. By contrast, in our context, the monetary authority knows that it will be present forever, but also recognizes that private agents are skeptical about its identity and behavior.

There is an inflation bias from lack of commitment as in many macroeconomic models. When $\rho = 0$, the inflation bias is $\mu = 1\%$ or about four percent per year. With ρ changing continuously between 0 and 1, the extent of this bias changes smoothly. At our fifty-fifty reference case of $\rho = .5$, note that steady state inflation is positive and, in fact, is higher than $.5 * \mu = 0.5\%$. Thus, our partial commitment model works differently from that of Schaumburg and Tambalotti [2007], where both the monetary authority and private agents correctly understand that there is a fixed exogenous probability of policymaker replacement each period and notably an optimal policy chooses a zero inflation rate if policymaker replacement does not occur (which would imply $a_t^{\tau=1} = 0$ in our framework).

¹⁸While the recursive approach is general enough 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 rules a, γ, x under constant credibility, as shown in Appendix B.

In our setup, the policymaker's calculus is based on his knowledge that he will always be in place, but also that there will always be private sector skepticism about whether inflation will evolve according to his plan. He therefore more than accommodates the adverse inflation shift in inflation expectations, $(1 - \rho)\mu$. As shown in Figure 3.2, this accommodation is a general result for all levels of credibility. To understand why, notice that the authority has an expected inflation $E_t\pi_{t+1} = \rho Ea_{t+1}^{\tau=1}|(s_t) + (1 - \rho)\mu$ and a Phillips curve trade-off

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

since the assumption about the benchmark alternative type implies that $l = \rho$. It faces a higher intercept of that trade-off ($\beta(1 - \rho)\mu$ rather than 0 without skepticism) and also a worsened slope in terms of the effects of expectation management ($\beta\rho$ rather than β without skepticism).

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 smaller degree of leverage that the authority has over expected inflation. Put alternatively, 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 rate depending reversely on the level of credibility.

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

3.2 Benchmark alternative type

The dynamics arising with endogenous credibility are remarkably different from those just considered with exogenous, constant credibility in the prior subsection.

Fifty-fifty: Consider first a monetary authority which starts with $\rho = .5$, i.e., private agents believe that there is a 50% likelihood that they are facing a policymaker of either type. With exogenous credibility in Figure 3.1, we saw that the optimal policy involved an initial inflation rate of about 3.6% which was gradually reduced to a long-run rate of 2.9%.

The results with endogenous credibility are sharply different, both in the short-run and the long-run, as can be see by looking at the ‘ $\diamond$ ’ path in panel A of Figure 3.2. The monetary authority chooses to eliminate inflation immediately (its initial action $a^{\tau=1}$ is close to zero) and to follow up with deflationary actions: these are taken so as to build its reputation, which rises sharply in Panel C (reaching $\rho = .9$ within a year). Its ability to invest in reputation means that it asymptotically chooses zero inflation, in contrast to its choice of a

positive inflation rate in the exogenous reputation case that was displayed in Figure 3.1.¹⁹

Thus, in the fifty-fifty case, endogenous credibility overturns both key implications of the NK model with optimal policy choice in the presence of skepticism: there is no start-up inflation and there is no long-run inflation.

Turning to the details of the transitional dynamics, we see that expected inflation is dramatically affected by the endogeneity of reputation, since private agents understand that a committed authority will take tough actions: panel B shows that it is about 1% in the first period, zero in the second period, and turns negative thereafter. But, 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 about -6%, with a gradual recovery taking place over a year). The persistently low level of output reflects the tough actions taken by the monetary authority and skepticism that private agents hold toward these actions, which are resolved only after a year or so.

Stronger initial reputation: Similar outcomes arise when the monetary authority has a stronger initial reputation ($\rho = .75$, illustrated with a ‘ $\triangle$ ’ in Figure 3.2 and others below). With less of an investment in reputation to be accomplished, the optimal policy actions are somewhat less restrictive than those the fifty-fifty case, but muted in magnitude. As in the fifty-fifty case, the desirability of investing in reputation leads to the elimination of the initial interval of "start-up" inflation that arises under optimal policy with credibility.

Weaker initial reputation: A very different dynamic path arises when the monetary authority has a weaker initial reputation ($\rho = .25$; paths indicated by (‘ ∇ ’): there is an initial interval of inflation, resembling the start-up solution for several periods. But the motivation for the gradual reduction in inflation appears to us to be very different in these two situations. For the policy maker with full commitment, a modest boom is created by having the expected rate of inflation below the current rate of inflation (see the ‘*’ path in Figure 3.2).

By contrast, for the policymaker with a weak initial reputation ($\rho = .25$), inflation expectations are relatively insensitive to his policy action. Hence, an aggressive reduction in inflation – say, a "cold turkey" zero inflation solution – is simply too costly in terms of output. Even under the optimal policy, a deep recession occurs, with an 8 percent output gap arising for the first year.

In the standard analysis of policy without credibility, the monetary authority is unwilling to fight inflation – when it is at its equilibrium value – because there would be output losses

¹⁹A 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

from doing so. It takes inflation expectations as unaffected by its policy actions. The monetary authority with weak initial reputation does not suffer from a commitment problem in our framework. However, it does face skepticism concerning its inflation plans manifested in a reduced leverage on expectations, i.e., it has imperfect credibility. Accordingly, its optimal commitment policy is to gradually reduce inflation as it balances output losses and credibility building.

To sum up, the startup inflation mechanism that explores the initial conditions and is aimed at a boom in NK model is 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 – an approach of dramatic policy actions – advocated by Sargent (1982, 1983) as a means of building credibility/reputation for low inflation.

3.3 Diagnostic model variations

Endogenous credibility can have substantial implications for the behavior of inflation and real activity under optimal policy, given the results reported in the previous subsection. To understand why, we now explore alterations in structural elements of our endogenous credibility model including analysis of "tag-along" behavior of the alternative policymaker.

As discussed at the end of section 2, credibility interacts with policy within two components of our model. First, credibility affects the influence of expected future policy in the inflation equation (7). Relative to the benchmark studied in the last section, we can restore the complete leverage that the monetary authority has by adjusting the value of ω to one in this equation. For concreteness, call the value of ω in this equation ω_p , so

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

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 (8), but this effect is shut-down if ω is set to one. For concreteness, call the value of ω in this equation ω_b , so

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

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 our tag-along behavior. Using this approach, we thus study the three cases displayed in Table 5.1.

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, which can be accomplished by setting the parameter $\omega_b = 1$ while keeping the parameter $\omega_p = 0$. This is closely related conceptually to the exogenous credibility analysis of section 3 but there is one crucial difference: while credibility is unaffected by the policy action, it is not constant over time but rather evolves according to the difference equation that is Bayes' law. Panel C of Figure 3.3 shows that the evolution of reputation depends substantially on the initial condition: it is quite fast for $\rho_0 = .75$ (so that ρ is nearly one after two years) and quite slow for $\rho_0 = .25$ (so that ρ attains .4 only after four years).

There were two key aspects of our section 3.2 analysis of optimal policy with a benchmark alternative and endogenous credibility, relative to the constant exogenous credibility models of section 3.1: an 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 credibility solution, being most inflationary for low credibility (this finding harks back to the constant exogenous credibility case of section 3.1).

But, so long as $\rho_0 > 0$, reputation will asymptotically approach 1. Hence, the zero long-run inflation implication is obtained in all cases. In the fifty-fifty case, the optimal policy is to reduce inflation from about 2.8% to about 0% over roughly a year with a inflation falling by roughly 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 a never a deflation. Put alternatively, the diagnostic experiment in this subsection confirms our earlier assertion that it is policy concern about learning which makes it 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 effect of credibility on expectations leverage

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 of section 4 (setting $\omega_b = 0$).

In isolation, strengthening the monetary authority's leverage on expected inflation makes it more desirable for the policy authority to have a gradual reduction in inflation. (Recall from section 3 that a permanent increase in credibility led to a greater initial inflation rate – relative to the relevant steady state – and a more measured reduction in inflation). Looking

at the $\rho_0 = .25$ optimal policy path in Figure 3.4 and then comparing it to that in Figure 3.2, notably, we see that greater expectations leverage leads to greater inflation in the early stages of the plan – about 2% rather than just over 1% – as well as a more rapid movement to an interval of deflation and it is somewhat more severe with increased leverage. The greater leverage in Figure 3.4 does lead to smaller output losses during the transition to price stability, but it does not eliminate these disinflation costs because there remains the level effect of imperfect credibility on the trade-off between inflation and output.

Taking the two of our diagnostic experiments together, we find that the key mechanisms determining the nature of the optimal policy in 3.2 are: 1) Costs of imperfectly credible disinflation due to the level effect of credibility in the inflation-output trade-off, and 2) Desirability of investing in reputation due to the marginal learning effect of policy actions. We thus conclude that the learning mechanism is the main structural feature which leads to the nature of optimal policy within the benchmark endogenous credibility model, which features a benchmark alternative.

3.4 Tagalong alternative type

Much of the prior literature on reputational mechanisms in macroeconomic policy focuses on the incentives that these provide for a weak policymaker to behave in the same manner as a strong one. For example, building on the "chain store" results of Kreps and Wilson [1982] and Milgrom and Roberts [1982], Backus and Driffill [1985a,b] and Barro [1986] showed that a weak policymaker can be led to adopt the zero inflation policy of an automaton strong type until the later stages of a finite horizon game.²⁰

In this subsection, we suppose that the alternative monetary authority follows a tag-along behavioral rule, of the form $a^{\tau=2} = a^{\tau=1} + \hat{\mu} + \hat{\phi}\varsigma_t$. This ad hoc rule is chosen to represent, in a simple and transparent manner, the potential implications of policy mimicking as described in the earlier literature.²¹

We first set $\hat{\mu} = \mu$ so that the inflation bias arising from lack of commitment is adjusted one-for-one with the policy action of the committed authority.²² Figure 3.5 shows that the results of policy mimicking by the alternative type can be dramatic for the committed monetary authority: at all levels of credibility, there is a gradualist policy for inflation. As

²⁰A recent development in reputation literature by Cripps, Mailath and Samuelson (2004) shows that introducing imperfect monitoring in an infinite-horizon game undermines the incentive of the weak type to mimic in the long run. However, mimicking can still be a short-run phenomenon. In addition, the long-run mimicking behavior can be restored if the type of the long-lived player is governed by a stochastic process. See for example, Mailath and Samuelson (2001).

²¹A more complete analysis of this topic will require developments along lines that we are pursuing in companion work.

²²The value of ϕ is irrelevant here since the inflation shocks ς_t are set to be zero at all periods.

shown in the diagnostic experiments (section 3.3.1) in the previous subsection, the tagalong feature of the alternative type eliminates the effect of the committed type's policy action on the private sector's learning. When the policy cannot affect learning, it then takes the form of "gradualism" which were indeed an alternative disinflation strategy endorsed by many economists including Monetarists like Friedman, Brunner, Meltzer, and etc.

In contrast to section 3.3.1, mimicking by the alternative type lends the committed monetary authority extra leverage on the private sector's inflation expectations. In particular, regardless of its initial reputation, the committed type has full leverage over the expected inflation, which further enhances its incentive to conduct a disinflation policy at the startup. However, imperfect credibility does have an impact on the optimal policy through the level effect $(1 - \rho) \hat{\mu}$. This level effect makes the optimal policy more accommodative in the initial period and the output costs of disinflation more severe when the initial reputation is lower.

In real terms, the full leverage on inflation expectations yields a stimulative credible disinflation effect and the level effect of imperfect credibility results in a contractionary incredible disinflation effect in 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 the Volcker disinflation. For our lower level of initial credibility ($\rho_0 = .25$), the two effects cancel out in the initial period, with the economy subsequently displaying declining inflation and an intensifying recession.

Notice that learning is faster in the cases of $\rho_0 = 0.5$ and 0.75 when the alternative type is mimicking than when it adopts a fixed action in the benchmark case. This counterintuitive result is due to the relatively large gap between $a^{\tau=1}$ and $a^{\tau=2}$ in the case of a tagalong alternative type, in which we set $\hat{\mu}$ equal to the inflation bias under full discretion (4% annual inflation rate). It is thus interesting to explore the consequences when we vary the extent to which the alternative type can mimic the committed type's policy action. To this end, Figure 3.6 shows the results with $\hat{\mu} = 0.5\mu$ that is half size of the inflation bias under full discretion (2% annual inflation rate): a notable consequence is that learning is slower than in the benchmark case with all levels of initial reputation. Slower learning leads to more stubborn dynamics of expected inflation and in turn larger loss in output along the disinflation path.

The comparison between two cases with different levels of $\hat{\mu}$ makes it clear that mimicking by the alternative type is a double-edge sword. On the one hand, it endows the committed type with better control over the inflation expectations, as its leverage is larger. On the other hand, mimicking may slow down learning, which hurts 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 a regular occurrence that a central bank misses the midpoint of the target range, by a small or large amount. There thus emerges a natural question: 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 deals with this question by studying the optimal response to a one-time implementation error in our model.

Another classic question in the NK literature and also 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 inflation shock ς_t in the Phillips curve as such a shock. In the second part of this section, we study the consequence of a persistent inflation shock at different levels of credibility.

All of the results in this section are to be interpreted as an impulse response, 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 magnitude one percent annually (0.25% quarterly). Figure 4.1 plots the impulse responses under full reputation and under zero reputation. Similar to the transitional dynamics, we do not need to distinguish model variations since without change in reputation, the dynamics are all the same.²³ Several remarks follow.

First, the implementation error occurs after the policy action a_t so that there is no initial period policy response in panel A or in the predetermined reputation state variable ρ_t in panel C.

Second, with full reputation, the effect of a positive one-time unexpected implementation error ε_t is to increase output if expected inflation is held fixed, according to the Phillips curve

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

Given that the policy action is taken before the realization of the implementation error, the only control that the committed monetary authority had over the response of the 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

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

inflation in subsequent periods. In fact, 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 the 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. That is, in the full reputation case, 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 policy authority has no influence on expectations and in turn, 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.

Now we turn to cases with initial reputation level between 0 and 1. Figures 4.2 and 4.3 compare the impulse responses in three model variations, each from a particular initial reputation $\rho_0 = 0.5$ and 0.25. We leave out the case with $\rho_0 = 0.75$ since the results are qualitatively similar to the case with $\rho_0 = 0.5$.

4.1.1 Constant credibility

It turns out that the equivalence between startup and implementation error responses in full reputation case carries over to situations with alternative constant levels of credibility, although the strength is diminishing in ρ . As in the discussion of transitional dynamics, the weakened response – less persistent startup disinflation and less persistent policy response to implementation shocks – reflects the fact that the policymaker sees only part of expected inflation responding to his policy actions. Suppose an implementation error occurred last period $\pi_{t-1} = a_{t-1} + \varepsilon_{t-1}$, 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 to offset ε_{t-1} when $\rho < 1$. As a result, with a lower level of credibility, the real effect is larger on impact and is less smoothed out over time.

4.1.2 Tagalong alternative type

As explained in the previous section, the tagalong behavior of the alternative type suppresses the effect of policy on learning, which makes this case similar to the constant credibility case with two differences:

One difference lies in the monetary authority's leverage over the expected inflation. Knowing the alternative type will mimic its inflation action, the committed type has full leverage on expectation despite its imperfect credibility. As a result, the policy response

to the one-time implementation error is almost identical across different initial reputation conditions. That is, policy mimicking of the tag-along variety leads to a protracted increase in the path of the inflation action, which has an initial stimulative effect on the output.

The other difference stems from the private sector's learning. A positive implementation error makes the realized inflation unexpectedly higher than the committed type's inflation action, which then results in a downward revision of the private sector's probability that it is the committed monetary authority in place, according to the Bayes' rule (8). Although the loss in reputation is independent of the policy action, it does depend on the initial reputation level. The policymaker with lower initial reputation incurs larger loss in reputation and in turn suffers more from the level effect of the imperfect credibility. This channel is captured by the response of expected inflation plotted in Panel B: the expected inflation is more stubborn with lower initial reputation. Correspondingly, the initial positive output response is followed by a small recession.

4.1.3 Benchmark alternative type

Facing the private sector learning with a benchmark alternative type, the policy response of the committed monetary authority departs from its responses in the previous two cases.

Fifty-fifty: Let us start with the initial reputation of $\rho_0 = .5$. We see that optimal policy response allows expected inflation to rise in period 0, in part by increasing $a^{\tau=1}$ at date 1, so that the output effect of the implementation error is muted on impact just as in the full credibility case. However, there are new elements at work with $\rho_0 = .5$: the implementation error shock causes a decline in ρ_1 so that rebuilding of reputation will be necessary in the future. Because credibility has deteriorated, the policymaker accommodates at date 2 the higher expected inflation to avoid a too negative output gap; thereafter the investment in rebuilding of reputation starts. During this investment period, the committed monetary authority implements an aggressive disinflationary policy to better distinguish himself from the alternative type.

Weaker initial reputation: The policymaker with initial credibility of $\rho = .25$ behaves very differently. As shown in panel A of Figure 4.3, he allows the implementation error in period 0 to generate a positive movement in his action for the first four quarters after the shock. In terms of magnitudes, the one percent inflation shock at date 0 causes the policy action to be elevated by an average of one-half percent over the first four quarters. As in our analysis of Figure 3.2, the policymaker with weaker initial reputation is accommodative because he faces a very major upward shift in expected inflation, due to the decline in reputation.

Tougher policy actions would have adverse output effects that he seeks to avoid. Note

that he is already, in Figure 3.2, undertaking a gradual disinflation with substantial output costs. Consequently, the monetary authority invests less in reputation building for about a year when faced with a positive implementation error, prolonging the relatively lengthy reputation-building process in panel C of Figure 4.3.

4.2 Persistent inflation shock

We now turn to the effect of an inflation shock, ς_t , at date 0 with magnitude one percent annually (0.25% quarterly) and persistence .9.

Figure 4.4 plots the impulse responses under full reputation and zero reputation, which correspond to the full commitment solution and full discretion solution in the literature. This inflation shock has a contractionary effect in both cases. When there is no commitment, Clarida, Gali, and Gertler [1999] show that there is an inflation policy which depends only on ς_t since the policymaker has no control over expectations. Hence, the path of inflation action when $\rho = 0$ reflects the persistence of the shock.

When there is full commitment, optimal policy is a form of "flexible price level targeting"²⁴. Accordingly, the appendix shows that the coefficients of policy response to the current and lagged inflation shock are equal in absolute value and of opposite sign when $\rho = 1$, so that there is no long-run effects of these shocks on the price level under full commitment. In Panel A of Figure 4.4, the response of inflation action when $\rho = 1$ is first positive and then negative, reflecting the optimality of "flexible price level targeting".

The fact that optimal policy under full reputation responds to the lagged inflation shock stems from the ability of the monetary authority to reduce the expected inflation, which provides an additional channel to offset the effect of a positive inflation shock, compared to the monetary authority with zero reputation. Through this channel, the monetary authority with full reputation can better stabilize inflation and output after an inflation shock ς .²⁵

The impulse responses with $\rho_0 = 0.5$ and $\rho_0 = 0.25$ are plotted in Figures 4.5 and 4.6, respectively. Again, we leave out the case with $\rho_0 = 0.75$ due to its similarity to the $\rho_0 = 0.5$ case.

4.2.1 Constant credibility

Compared to the full reputation case, when ρ is fixed at an intermediate value, the monetary authority only has partial leverage over the inflation expectations, which weakens its ability

²⁴See King and Wolman [1999] and Woodford [2003] for early statements of the case for price stability made by this class of models and Gali [2008] for a textbook presentation.

²⁵That is, the extent of credibility affects the extent of "stabilization bias" as defined in the literature (e.g., Gali and Gertler [2007]) and discussed above.

to smooth out the effect of a positive inflation shock. Hence, the optimal policy and output responses with intermediate values of ρ lie between their counterparts in the full reputation and zero reputation cases. In particular, the optimal policy shifts from the "flexible price level targeting" to the "flexible inflation level targeting." The optimal output response is more front-loaded when the level of ρ is lower.

4.2.2 Benchmark alternative type

When the reputation is endogenous, the inflation shock makes a good opportunity for the committed type to invest in reputation since the alternative type responds to the inflation shock with a coefficient equal to 1.98, which effectively adds 2% annual inflation over the 4% inflation bias. As a result, the inflation actions taken by the committed type are less responsive to the inflation shock as compared to those in the constant credibility case, where learning is not relevant. The gain in reputation is reflected in Panel C and is particularly pronounced with weaker initial reputation ($\rho_0 = 0.25$).

Due to the reputation building, the expected inflation is dragged down compared to the constant credibility case. This leads to a gain in output in all cases with intermediate values of ρ_0 and in all periods, reflected in Panel D. The large movements in expected inflation and output in the case of $\rho_0 = .25$ are due to the fact that the impulse responses are plotted as the differences from the transitional dynamics in Figure 3.2, in which there is no cost-push shock, when the expected inflation is stubbornly positive and the output is particular low around date 3.

4.2.3 Tagalong alternative type

When the alternative type mimics, it gives the committed monetary authority full leverage over expectations, which makes it able to anchor the expected inflation better and thus perform more aggressive disinflation than it does in the constant credibility case, with an aim of stabilizing output response.

Learning in the case is a by-product of the inflation shock since it enlarges the inflation premium of alternative type ($\mu + \phi_{\varsigma_t}$) and in turn helps the private sector learn faster according to the Bayes' rule (8). The extra gain in reputation reinforces the aggressiveness in disinflation and the stabilization of the output. Interestingly, the lower is ρ_0 , the larger is the gain in reputation. This result appears similar to the benchmark alternative case studied in the previous subsection but it occurs for a different reason. There, it is because of active reputation building by the committed type through implementing tougher inflation actions. Here, although the difference between policy actions of the committed and alternative types is

the same across various initial reputations, a lower ρ_0 results in a faster growth in reputation as a result of the Bayes' rule.

5 Alternative-type monetary authority histories

The implications of the dynamic monetary policy framework discussed in sections 3 and 4 have so far been studied under the assumption that policy is conducted optimally by the committed type. It is of interest to also consider experiments with inflation decisions made by alternative types of monetary authorities. Relative to the experiments so far, each of these is a particular counterfactual, but each is a counterfactual that is very relevant to the agents in the economy.

5.1 A full sample counterfactual

How would output, inflation, and other variables behave if there were a monetary authority of the alternative type in place starting at date 0? To illustrate the outcomes, we compute the specific sample path with no implementation errors ($\varepsilon = 0$) and no structural inflation shocks ($\varsigma = 0$) similar to that which we explored in section 3 above. To be more specific, we assume that $\pi = a^{\tau=2}$ at all dates, replacing our earlier assumption that $\pi = a^{\tau=1}$ at all dates. To calculate output x , inflationary expectations e , reputation (ρ') and the commitment state variable (η'), we evaluate the functions (14), (11), and (15) at that inflation rate. We explore only the benchmark alternative in this section, presenting the results for other alternative types in appendices.

The analysis of this counterfactual requires two aspects of our prior results: the transitional dynamics analysis of section 3 is relevant as we considering variants of that start-up situation, while the response to implementation errors of section 4 is relevant because rational formation of inflation expectations – calculation of $e(\rho_t, \eta_t, \varsigma_t, \pi_t) = E_t \pi_{t+1} = \rho_{t+1} E_t \pi_{t+1}^{\tau=1} + (1 - \rho_{t+1}) E_t \pi_{t+1}^{\tau=2}$ – requires that private agents envision how a committed monetary authority would respond to the same inflation history, which it would encounter only as a series of large positive inflation implementation errors.

Figure 5.1 shows the behavior of inflation expectations, output, and reputation under the assumption that inflation is always at the level of $a^{\tau=2} = 4\%$ chosen by the benchmark alternative monetary authority. Along this path, inflation is systematically higher than expected inflation ($\pi = a^{\tau=2} > e$) as is shown in panel A. Experiencing surprisingly high inflation each period ($\pi = a^{\tau=2} > a^{\tau=1}$), agents lower the likelihood which they attach to a

committed monetary authority being in place ($\rho' < \rho$).²⁶ The path of reputation is shown in panel B of Figure 5.1: there is a rapid decline, but a lengthy period for which $\rho > .10$ due to a shrinking gap between the committed policy action and the one implemented by the alternative type which slows down the learning process. Given that actual inflation exceeds expected inflation, the economy experiences a protracted real expansion which fades away as inflation expectations rise, displayed in Panel C.

The behavior of the committed monetary authority confronted with the same set of experiences (a series of large positive implementation errors) is shown in panel D, for various levels of credibility. It is useful to start by considering the full commitment case $\rho_0 = 1$: in the face of a positive implementation error $\varepsilon = \mu > 0$, the committed monetary authority seeks to smooth out the effect of this temporary shock on output, by tolerating a sustained rise in inflation, while planning for a return to zero inflation (recall the discussion of section 4.1 above). So, it is natural that the initial policy action involves an increase in the inflation target. However, in the particular counterfactual which we are exploring, the committed authority is hit with a series of positive shocks of amount $\mu - a^{\tau=1} > 0$ so that it is continually targeting high inflation (about 2%) that it intends to bring down, but keeps getting hit by a positive shock. At lower levels of credibility, as we have seen previously in section 3, it initially embarks on an anti-inflation campaign that targets low inflation (in the ballpark of 0 to 1 percent, depending on initial credibility). However, as its reputation deteriorates, it faces rising inflation expectations and reduced leverage over inflation expectations. Ultimately, it partly accommodates, with its inflation target rising to close to 3 percent as the reputation level falls to the neighborhood of .10. It is important to note, however, if the implementation errors were to disappear, then the committed type would again embark on an anti-inflation campaign of a form which depended on its inherited credibility. This committed-type behavior is important with the benchmark alternative setting solely because it affects expected inflation (which is $E_t \pi_{t+1} = \rho_{t+1} E_t \pi_{t+1}^{\tau=1} + (1 - \rho_{t+1}) E_t \pi_{t+1}^{\tau=2} = e(\rho_t, \eta_t, \varsigma_t, \pi_t = a_t^{\tau=2})$ and is shown in panel A) and consequently output (panel C).

Taking the full set of results into account, the alternative monetary policy brings about high inflation, increasing expected inflation that approaches the inflation bias of 4%, a declining reputation for trustworthiness in terms of delivering on inflation targets, and a temporary real stimulation. In terms of interpretation of disinflation experiences, we think of this as a public event indicating a policy regime change after a lengthy interval of high inflation,

²⁶That is, they find it less likely that there has been an inflation implementation error equal to $\varepsilon = a^w - a^s = \mu - a^s(\rho, \eta, \varsigma)$, as is required if the observed inflation is generated by the strong authority, than that there has been an error of zero, as is required if inflation is generated by the weak authority. Consequently, they lower their posterior value of ρ' relative to the prior ρ .

to which a likelihood of ρ_0 is attached to the change involving a move to a committed and trustworthy authority. We are then considering how the economy responds if there is no change in inflation, which is that there is a temporary decline in inflation expectations and a temporary real expansion relative to the pre-regime-change era.

There are two useful interpretations of this counterfactual. One is that it represents, with a particular series of inflation implementation errors ($\pi = \varepsilon = a^{\tau=2}$) that concern private agents and which thus figure in the committed monetary authority's policy design. The other is that it is a history with an actual benchmark alternative authority in place ($\varepsilon = 0$ and $\pi = a^{\tau=2}$). From the perspective of the private agents in the economy, these two interpretations are observationally equivalent.

5.2 A series of one-step-ahead counterfactuals

We now envision a different counterfactual: we imagine that inflation outcomes are generated by the committed type with zero realized implementation error ($\pi = a^{\tau=1}$) just as we did in the section 3 treatment of start-up dynamics. We then ask, "given the inflation history experienced through period t , if an alternative type authority chose the inflation rate, then what would happen?" These experiments are particularly important for the behavior of interest rates generated by a committed monetary authority's optimal inflation targets in a setting of skepticism, because private agents attach a likelihood to such a situation arising.

Mechanically, we determine the path from the start-up date just as in section 3 and we then compute the current output under the alternative type action but without implementation error,

$$x(\rho_t, \eta_t, \varsigma_t, \pi_t = a_t^{\tau=2})$$

We also calculate the expected future output under the assumption that current inflation is set by the committed type, but that future inflation will be set by the alternative type, i.e.,

$$E_t x(\rho_{t+1}, \eta_{t+1}, \varsigma_{t+1}, \pi_{t+1} = a_{t+1}^{\tau=2} + \varepsilon_{t+1})$$

This is an expectation that is relevant for real interest rate determination when the committed monetary authority is in place, but private agents are somewhat skeptical.²⁷

²⁷This conditional expectation is, more precisely,

$$\int \left[\int x(\rho_{t+1}, \eta_{t+1}, \varsigma_{t+1}, a^{\tau=2}(\rho_{t+1}, \eta_{t+1}, \varsigma_{t+1}) + \varepsilon_{t+1}) \delta(\varepsilon_{t+1}) d\varepsilon_{t+1} \right] d\Phi(\varsigma_{t+1}; \varsigma_t)$$

with $\rho_{t+1} = b(\rho_t, \pi_t; a^{\tau=1}(\rho_t, \eta_t, \varsigma_t), a^{\tau=2}(\rho_t, \eta_t, \varsigma_t))$ and $\eta_{t+1} = \gamma(\rho_t, \eta_t, \varsigma_t, \pi_t)$ both functions of information on which E_t is based.

5.2.1 Benchmark alternative type

We have previously described the behavior of output under the committed type's optimal policy when $\pi = a^{\tau=1}$ in Section 3.2, a reference path included as Panel A of Figure 5.2. At each date, given the inflation history $\pi_k = a_k^{\tau=1}$ for each date $k < t$, Panel B shows the output that would arise if a benchmark alternative type were in place just for that period, which is $x(\rho_t, \eta_t, \varsigma_t, \pi_t = a_t^{\tau=2})$. It displays a key property of the model with imperfect credibility: an expansion will occur if monetary policy is relaxed, with a magnitude which depends on the extent of credibility (as summarized by ρ) and also on the inflation history since the startup date (as reflected in the commitment multiplier η). Since $\varepsilon = 0$ and $\varsigma = 0$, this the most likely output level.

The lower two panels show, respectively, the expectation of output $E_t x_{t+1}$ which would arise under a committed type (panel C) and a benchmark alternative type (panel D). If the x function were linear in ς and ε , then Panel C would just contain the same information as Panel A, but simply shifted left by one period, since each represents output under the committed type. Similarly, Panel D would just be panel B shifted left one period. However, due to the nonlinearity of the effects of the shocks ς and ε on output which arises from endogenous learning, the expected future output is different from the most likely future output level shown in the top panel.

5.2.2 Tag-along alternative type

We next consider the real consequences of an alternative monetary authority of the tag-along type, using Figure 5.3 which is constructed in the same manner as Figure 5.2. Panel A shows the behavior output under the committed type, mirroring the information in our earlier Figure 3.5. Panel B displays output when inflation is set at the tagalong-alternative-type's action, $a_t^{\tau=2} = a_t^{\tau=1} + \mu$, in each period but the history through date $t-1$ is $\pi = a^{\tau=1}$ (the same history as used to construct panel A). Output is higher than its counterpart in panel A by 12%, reflecting the real effect of a quarterly inflation rate that is 1% and a Phillips curve slope which is approximately $1/12$. Panel C shows expected output $E_t x_{t+1}$ under the committed monetary action next period, while Panel D shows expected future output if there is a tagalong-alternative-type monetary action next period. All of the panels look pretty much the same, except that the time scale is shifted by one from A to C and B to D, while the intercept is shifted by 12 from A to B and C to D. As we stressed in section 3, the tag-along alternative has the force of increasing the leverage that the committed policymaker has on inflation expectations, while mitigating the marginal effects of policy on learning. In this case, the most likely future output (in panels A and B) is a good guide to expected

future output (in panels C and D), which highlights the fact that the nonlinearity which drives a wedge between these two constructions is associated with the effects of shocks on learning.

6 Interest rates and interest rate targets

We now investigate the comovement of various interest rates with inflation, output, credibility and reputation, as well as the construction of an interest rate target consistent with the inflation target $a^{\tau=1}$. To do so, 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 these are conditional on realized inflation π as well as the initial state of the economy at the start of the period (ρ, η, ς)) and we second consider markets which are contemporaneous with the policy decision (which just depend on (ρ, η, ς)). We call these 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 a unit of goods or assets in the end of period market at t .

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

Consider first a one period real and nominal discount bond traded in the end-of-period market at t . These assets will be priced on the basis of the inflation realization as well as the state variables so that we find it convenient to define the expectation operator E_t^+ that conditions on the end-of-period information set $(\rho_t, \eta_t, \varsigma_t, \pi_t)$. For the real and nominal bond, loglinear approximation asset pricing formulae provide the familiar IS and Fisher equations of the NK model,

$$r_1(\rho_t, \eta_t, \varsigma_t, \pi_t) = r + \sigma[E_t^+ x_{t+1} - x_t] \quad (16)$$

$$i_1(\rho_t, \eta_t, \varsigma_t, \pi_t) = r_{1t} + E_t^+ \pi_{t+1} \quad (17)$$

²⁸By doing so, we abstain from considering possibly interesting interactions between risk premia and shifting beliefs about the type of the monetary authority.

However, our assumption also 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 $\rho_t, \eta_t, \varsigma_t$, which itself evolved according to a nonlinear vector stochastic difference equation, as well as the implementation error. These nonlinearities can be important for the behavior of interest rates, even when there are no risk premia as in the loglinear asset pricing framework which we employ.

where $r = -\log(\beta)$.

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

Consider next a futures contract in the start-of-period market at t to trade one unit of goods for a one period real or nominal bond in the end-of-period market. For these assets, loglinear asset pricing formulae provide *ex ante* versions of the familiar IS and Fisher equations of the NK model,

$$R_1(\rho_t, \eta_t, \varsigma_t) = r + \sigma[E_t x_{t+1} - x_t] \quad (18)$$

$$I_1(\rho_t, \eta_t, \varsigma_t) = R_{1t} + E_t \pi_{t+1} \quad (19)$$

Notice that In the two expressions above, the expectation operator E_t differs from E_t^+ since the start-of-period information set does not contain the realized inflation. Within the log-linear asset pricing framework, $R_{1t} = E_t r_{1t}$ and $I_{1t} = E_t i_{1t}$.

6.3 Interest rates during the startup interval

We now display the dynamics of the short-term interest rates implied by the inflation and output in the startup episode studied in section 3.

6.3.1 Full credibility

Under perfect credibility, the initial startup interval involves inflation and real activity which are both high – relative to their stationary values of zero – and falling. Accordingly, the real interest rate must be below its long-run level. Since there is expected inflation, the nominal rate will be above the real rate and may either be above or below its long-run level.²⁹

As discussed above, one interpretation of this initial startup interval is that it describes the consequences of replacing a monetary authority with no commitment with one that has complete commitment. Considering inflation and output paths in section 3, we noted that (i) the no commitment inflation rate is 4% with a close to zero output gap; and the (ii) the initial inflation rate under the commitment plan is less than 4%. Accordingly, under a

²⁹During the startup period, note that the real interest rate is negative: the growth rate of real output is negative, reflecting the temporary nature of the initial expansion, and this is sufficiently rapid to overcome a positive steady state rate. Moreover, the nominal interest rate under full commitment displayed in Figure 6.1 is negative, reflecting the dominance of the real rate movements over expected inflation during the start-up period. This finding, which highlights the fact that our computations do not impose a zero lower bound constraint, is actually a property of the startup dynamics of many New Keynesian models which have a "sufficiently distorted steady state"

perfectly credible disinflation, the nominal rate falls for two reasons: the real rate falls as a consequence of the temporary increases in real economic activity and the expected inflation rate falls as the optimal inflation path lies below the zero commitment level of 4%.

6.3.2 Imperfect credibility and end-of-period short term rates

Imperfect credibility can lead to very high real interest rates and nominal during a disinflation. The key mechanism is that current output is low, but private agents expect it to "snap back" to at least its normal level if an alternative policymaker is in place.

To illustrate the importance of imperfect credibility for the behavior of real and nominal interest rates during the startup interval, Figure 6.1 shows their behavior when the alternative monetary authority is the benchmark case..

By way of reference, the annual real interest rate implied by the discount factor is $r = 400 * -\log(\beta) = 2\%$ and the inflation bias is 4% (which is also the action of the benchmark alternative type). Thus, the reference no commitment equilibrium has an nominal interest rate of 6%.

There are staggeringly high real interest rates when agents are skeptical that there is a committed authority in place, but there is little initial credibility ($\rho_0 = .25$). While the stationary real rate is 4%, the real rate is over 30% in the first four quarters. Intuitively, with output low, the real interest rate is very high because the policy of the committed type makes current output low and because there is a large likelihood to future monetary policy being undertaken by an alternative type that will stimulate real activity above its sustainable level of $x = 0$. Thus, the real rate is high because there is a large expected growth rate of real output, $r_{1t} = r + \sigma[E_t^+ x_{t+1} - x_t]$. In Figure 5.2, under the committed type's policy in period 0, we saw that current output is reduced by about 8% for the first quarter and that this is also private agent's expected future output conditional on a continuation of strong policy. But, agents expect that there will be economic stimulation of about 4% conditional on an alternative type in place, an event which they expect with a probability of about .3, having seen one period's worth of tough policy (see Figure 3.2). Accordingly, the real interest rate $r_{1t} = r + \sigma[x_t - E_t^+ x_{t+1}]$ is about $r + (1 - \rho_{t+1})\sigma[E_t^+ x_{t+1}^{\tau=2} - x_t^{\tau=1}] = .02 + .7 * 1 * .12 = .10$ over a quarter or about 40% at an annual rate.

Expected inflation is initially about 2.5% when $\rho_0 = .25$, as may be verified by looking back at Figure 3.2, so that the nominal rate displayed in panel B of Figure 6.1 is higher than the real rate by that amount. However, the movements in expected inflation are dwarfed by the movements in expected real output growth and the real interest rate.

6.3.3 Imperfect credibility and start-of-period short term rates

Imperfect credibility can also lead to a major difference between relatively short-term rates due to anticipations about policy shifts. To illustrate this key mechanism, consider the real and nominal yields determined in the start-of-period markets. Expressions (18) and (16) imply that $R_{1t} = \rho_t E_t r_{1t}^{\tau=1} + (1 - \rho_t) E_t r_{1t}^{\tau=2}$, while expressions (17) and (19) imply that $I_{1t} = \rho_t E_t i_{1t}^{\tau=1} + (1 - \rho_t) E_t i_{1t}^{\tau=2}$. That is, each of these yields involves the start-of-period probability that committed and weak authorities are in place, as well as forecasts of the end-of-period interest rate that will prevail in each case.

Panels C and D of Figure 6.1 show that start-of-period real and nominal yields are much less variable than those in the end-of-period market. Considering first the real interest rate, we can understand this reduced variability by considering what will happen if a benchmark alternative-type monetary authority is in place: there will be a temporary real stimulation brought about by high inflation, which will lower the real interest rate. So, the start-of-period market yield incorporates this scenario, partially offsetting the high real rate that will arise with a committed authority. The start-of-period nominal rate is also affected by imperfect credibility because the alternative-type monetary authority chooses higher inflation than does the committed one. Breaking down expected inflation in (19) into its two components, $I_{1t} = R_{1t} + \rho_t E_t \pi_{t+1}^{\tau=1} + (1 - \rho_t) E_t \pi_{t+1}^{\tau=2}$, we can see that a lower level of reputation capital raises the weight on alternative-type expected inflation.

Previously, we discussed the idea that an imperfectly credible disinflation would lead to a higher real rate and a higher nominal interest rate than would have prevailed in an equilibrium without commitment. If we look at the rates in the start-of-period markets, the implications differ from those in the end-of-period markets. First, as discussed earlier, uncertainty about the type of the authority leads to weight being placed on the low real rates that will prevail with alternative-type monetary authorities and this effect can be sufficiently enough to mitigate or overturn the strong real rate that will prevail under the committed monetary authority, although we see high real rates during the bulk of the start up period from all initial levels of reputation. Second, the nominal interest rate during the transition can be lower or higher than that in the no commitment equilibrium due to different levels of expected inflation. However, in long run, the nominal rate converges at all initial levels of reputation to a rate lower than the rate without commitment since the committed type eventually gains full reputation as long as the initial reputation is nonzero.

6.3.4 Interest rates with a tagalong alternative authority

Figure 6.2 shows the behavior of real and nominal interest rates when the alternative policymaker is of the tag-along type, with a tag level of 0.5μ . There are four elements to stress. First, the real interest rate continues to be staggeringly high under optimal policy. Second, the dynamic paths for the real rate are quite different from those in Figure 6.1 for the benchmark alternative case, reflecting differences in the behavior of real output under the committed and (benchmark and tagalong) alternative types discussed in section 5. Third, from section 3, we know that expected inflation evolves quite sluggishly during the gradual disinflation associated with optimal policy with a tagalong alternative, so that the nominal interest rate adds such a component to the real rate. Fourth, the start-of-period rates are again less volatile, reflecting the likelihood that agents attach to alternative-type policy outcomes that will lower the real rate.

6.4 Short-term interest rate targets

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

Imperfect credibility leads to some tricky issues for an inflation targeting central bank. 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 $a^{\tau=1}$. In the US context institutional context, either of these measures could involve the location of the band for the Federal Funds rate, while $i_1(\rho, \eta, \varsigma, \pi)$ would represent the realized Funds rate.

However, these measures would not be the same as interest rates in start-of-period markets. In particular, consider the interest rate $I_1(\rho, \eta, \varsigma)$ calculated from the futures contract in the start-of-period market and whose behavior we just discussed. With imperfect credibility, this rate will differ from the monetary authority forecast, as $I_{1t} \approx \rho_t E_t i_{1t}^{\tau=1} + (1 - \rho_t) E_t i_{1t}^{\tau=2}$. By announcing an interest rate target of $E_t i_{1t}^{\tau=1}$, the monetary authority effectively says to the private sector: "my inflation target is a_1 and I forecast that the short-term nominal interest rate under that plan will be $E_t i_{1t}^{\tau=1}$. Given the imperfect credibility of that target, then I know that you are pricing assets in a manner which does not correspond to my plan."

In the US institutional context, the Fed Funds futures market deviates from the Federal Funds market itself, although this need not be a sign of imperfect credibility when the funds rate range is adjusted gradually over time to underlying economic conditions.³⁰

6.5 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 shock. More specifically, (17) provides an interest rate function

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

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

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

$$i_{1t}^\tau = i_1(\rho_t, \eta_t, \varsigma_t, \pi_t^\tau) + \theta_t^\tau [e_t - e(\rho_t, \eta_t, \varsigma_t, \pi_t^\tau)] \quad (20)$$

where e_t is 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 (these coefficients are subject to a restriction discussed in detail below). The uniqueness proof is given in Appendix E and covers a wide class of equilibrium stochastic processes for the New Keynesian model. A sufficient condition for a unique, stable rational expectations equilibrium under these interest rate rules is that the average response (across types) to out-of-equilibrium movements in expected inflation satisfies

$$\rho_t \theta_t^{\tau=1} + (1 - \rho_t) \theta_t^{\tau=2} > 1$$

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

$$\theta_t^{\tau=1} = \frac{\theta - (1 - \rho_t) \theta_t^{\tau=2}}{\rho_t}$$

for some $\theta > 1$. It is arguable that a type 2 monetary authority cannot specify how it will respond to out-of-equilibrium behavior of expected inflation, so that $\theta_t^{\tau=2}$ must be zero. There is a simple reputational equilibrium modification of the Taylor principle, with $\theta = \rho_t \theta_t^{\tau=1} > 1$:

³⁰In fact, Poole (date) argues that ...

less reputable committed monetary authorities must respond more dramatically to out-of-equilibrium movements in expected inflation in order to assure determinacy.

The outcomes of our model are thus observationally equivalent to ones from a model with the interest rate rule (20). However, with $\theta > 1$, we may discuss the workings of such an alternative economy with just the function $i_1(\rho_t, \eta_t, \varsigma_t, \pi_t)$ since out-of-equilibrium movements in expected inflation will never arise.³¹

6.6 Interest rate rule interpretation

To a first order approximation, the observed behavior of the interest rate is given by

$$i_t^1 = i_1(\rho_t, \eta_t, \varsigma_t, \pi_t = a_t^{\tau=1}) + \frac{\partial i_1(\rho_t, \eta_t, \varsigma_t, \pi_t)}{\partial \pi_t} \Big|_{\pi_t = a_t^{\tau=1}} * \varepsilon_t \quad (21)$$

$$i_t^2 = i_1(\rho_t, \eta_t, \varsigma_t, \pi_t = a_t^{\tau=1}) + \frac{\partial i_1(\rho_t, \eta_t, \varsigma_t, \pi_t)}{\partial \pi_t} \Big|_{\pi_t = a_t^{\tau=1}} * [\varepsilon_t + a_t^{\tau=2} - a_t^{\tau=1}] \quad (22)$$

for the two types of authorities (the approximation is taken around the level of i_1 arising under a type 1 authority). Note that transitory, unexpected inflation is associated with a decline in the nominal rate in the NK model, so that the partial derivative $\frac{\partial i_1(\rho_t, \eta_t, \varsigma_t, \pi_t)}{\partial \pi_t}$ is negative.

This approximation suggests that an econometrician observing our economy could interpret it as having interest rates governed by a rule with shocks and with "regime switches". Under this interpretation, equation (21) is the type 1 interest rate rule with shocks

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

Similarly, equation (22) 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. For the case of a benchmark alternative, the term $[a_t^{\tau=2} - a_t^{\tau=1}]$ is time-varying, while 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

³¹The proof in appendix E utilizes the logic described in King (2000) and in Cochrane (2011). King uses this form of analysis, as we do in this section, to describe how a particular monetary policy – neutral policy in his case, optimal policy in ours – can be supported by an interest rate rule coupled with a specified responses to deviations of inflation, expected inflation, or the price level from the desired outcomes. Cochrane uses the analysis, as we do in this section and the next, to establish observational equivalence of interest rate and other policies.

rate outcomes so as to determine whether they originated in ε_t or in $\varepsilon_t + [a_t^{\tau=2} - a_t^{\tau=1}]$ within (21) and (22), rather than working with inflation outcomes.³² 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 the Volcker disinflation within a calibrated New Keynesian model that has 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 over longer time periods.³³

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

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

with the former arising from rearrangement of the forward-looking constraint (3) and the latter deriving from the fact that $\eta_t = \gamma_{t-1}$ and there the optimization with respect to output in (9) requires the first order condition $-h(x_t - x^*) - \kappa\gamma_t = 0$. Hence, such an estimated rule would depend on current inflation and output, expected future inflation, and on past output. The Bayesian learning evolution would make ρ into a distributed lag of past inflation rates, possibly captured by a time-varying parameters in the estimated interest rate rule.

6.7 Reinterpreting inflation implementation errors

We now entertain the idea that implementation errors are not part of inflation control *per se*, but are the result of random shocks to the authority's objective that are its private information. By doing so, we move our analysis closer to other recent work on managing private sector beliefs (such as that of Mertens [2011]).³⁴ Specifically, suppose that we respecify our momentary objective (2) to

$$\begin{aligned}u(\pi_t, x_t) &= -\frac{1}{2}[(\pi_t)^2 + h(x_t - x^*)^2] \text{ if } \pi_t = a_t + \varepsilon_t \\ &= -\infty \text{ if } \pi_t \neq a_t + \varepsilon_t\end{aligned}$$

³²Moving between learning from inflation to learning from interest rates is somewhat subtle, as the interest rate is a nonlinear function of ε .

³³{Add Orphanides and Williams somehow?}

³⁴Mertens analyzes a setting in which the monetary authority without commitment capability has private information about the output gap which affects his optimal actions. The authority takes into account the effects of his actions on a measure of private sector beliefs.

so that there are urgent shocks to the authority's desired inflation rate. In terms of the timeline above, we assume that the preference shock is not realized until the end of the period, but that a policy announcement a must be taken at the start of the period. For the authority of type 1, inflation must be the announcement plus the shock since it is committed and trustworthy. The alternative authority is assumed to follow the same behavior rule as previously specified, either in the benchmark case or in the tagalong case.

Under this reinterpretation, there is no change in the pattern of private sector learning or any other feature of the equilibrium that we have described so far. One version of the policy announcement could be an inflation target (the mean of the inflation rate $a_t^{\tau=1}$ if a type 1 authority is in place). Another announcement could indicate the most likely level of the short-term interest rate in end-of-period markets, $i_1(\rho_t, \eta_t, \varsigma_t, \pi_t = a_t^{\tau=1})$, within the context of an overall interest rate rule that yields a unique equilibrium.³⁵ Under this reinterpretation, the ε_t could be viewed as leading to interest rate policy shocks, revealed to an econometrician as residuals from an estimated interest rate rule along the lines discussed in the prior subsection.

7 Summary and forward-looking statements

We have studied optimal monetary policy in a an imperfect public monitoring framework, where skeptical private agents learn rationally about the nature of the monetary authority and the monetary chooses its actions taking into account private sector learning.³⁶ Our focus was on issues of imperfect credibility that are plausibly relevant for the 1970s through the early 2000s, in that we examined disinflation dynamics and stabilization policy. 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 concerned about a mechanically inflationary alternative monetary authority (the benchmark alternative) or about one which would mimic the committed decisionmaker's actions (the tag-along alternative). This reinforces our view that an understanding of optimal policy under imperfect credibility requires an analysis of the type of strategic interaction between types of policy authorities that we have begun to examine in companion research.

³⁵However, this announcement structure would require that there be a one-to-one relationship between a_1 and i_1 . Think about this

³⁶We adopted the imperfect public monitoring framework for three reasons. First, it seems to us to capture actual aspects of the real world, where the private sector does not know the exact actions taken by a monetary authority, even one that operates under an interest rate rule because policy is multidimensional even in that setting. Second, in an imperfect public monitoring setting, there is the potential for reputation to rise and fall as a result of shocks even without changes in underlying policymaker behavior. Third, it complements other work on investment in reputation that we have done with other assumptions, including the use of mixed strategies in Lu [2012] and the use of stochastic heterogeneity of the alternative type (King, Lu, and Pasten [2008]).

Recent events in advanced economies have placed alternative challenges in front of the world's central banks, in both the conduct of monetary and banking policy. Notably, the difficulties of conducting monetary and banking policy at the zero lower bound as well as the ongoing challenges to the European monetary system are evidently very different from the problems of the 1980s. Yet, we see issues of imperfect credibility as central to each of these more recent developments, so that these also motivate our inquiries into the design of optimal policy in settings with 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 inflation shock	.9
σ_{ς}		Std of inflation shock	.02
σ_{ε}		Std of implementation error	.01

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)	Inflation shock
a^{τ}	(4)	Type-specific policy action
ε	(4)	Implementation error
ρ	(5)	Credibility
s	(6)	True state of the economy
γ	(9)	Commitment multiplier
η	(9)	Pseudo-state variable
Ω	(9)	Intermediate value function
W	(9)	Value function
m	Appendix A	Short-hand for $E\pi_{t+1} a^{\tau=2}$
F	(12)	cdf for implementation error
b	(5)	Bayesian updating function

Table 2.1

Case	Figure	ω_p	ω_b
benchmark alternative	3.2	0	0
no learning effect of policy actions	3.3	0	1
no leverage loss from imperfect credibility	3.4	1	0
tag-along alternative	3.5,3.6	1	1

Table 5.1

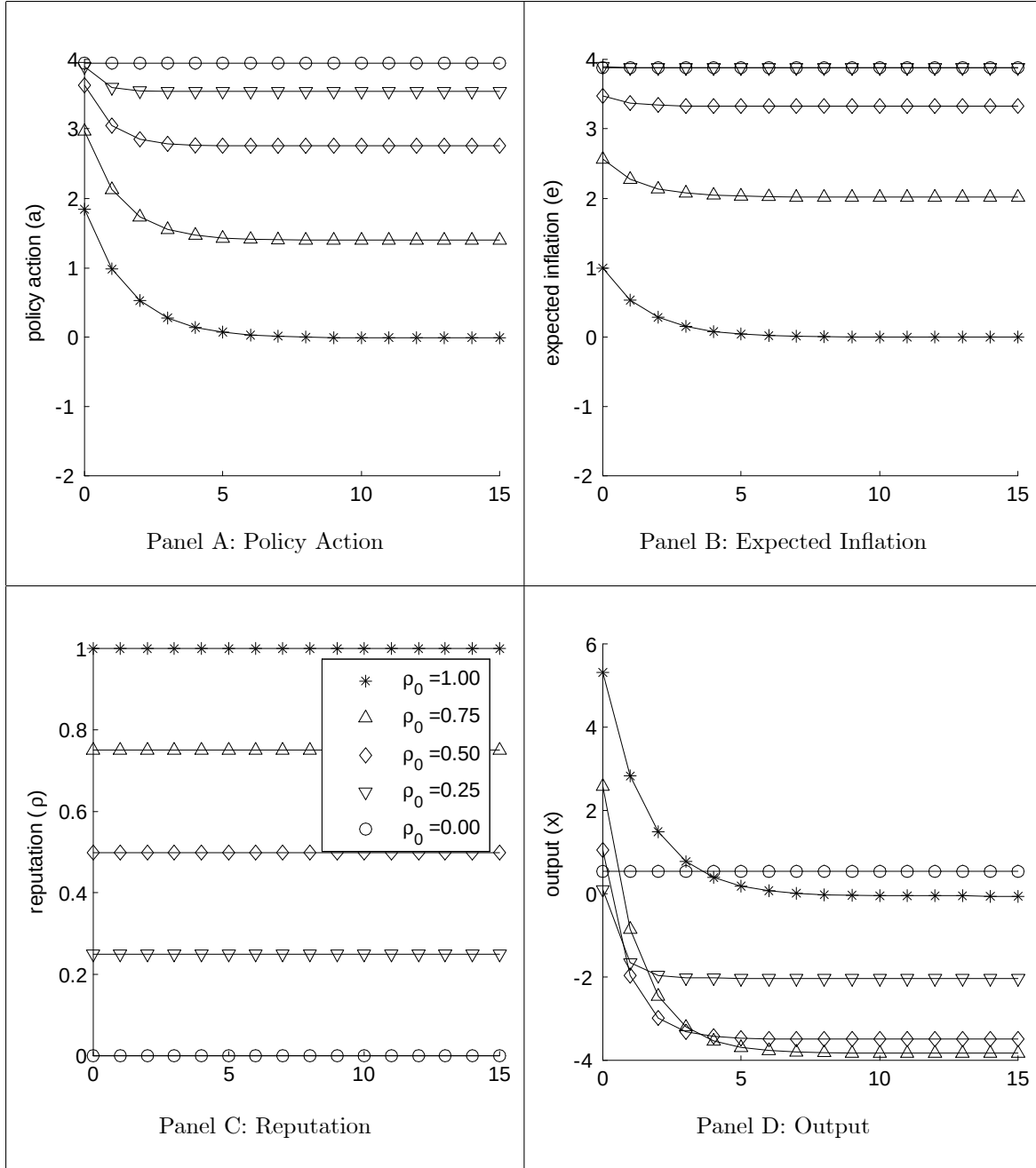


Figure 3.1: Startup dynamics with a benchmark alternative policymaker and exogenous, constant reputation. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

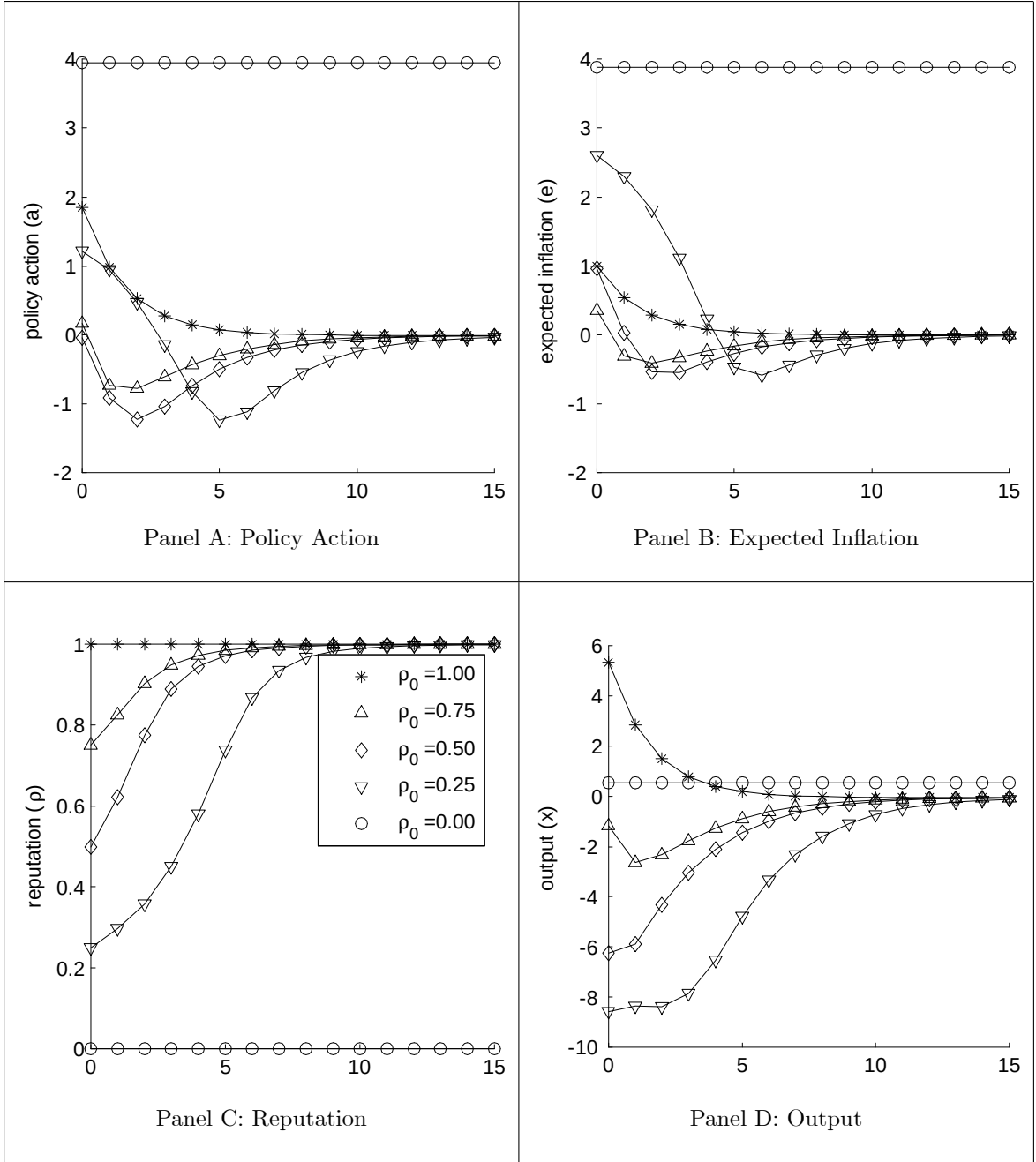


Figure 3.2: Startup dynamics with a benchmark alternative policymaker and endogenous reputation. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place.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

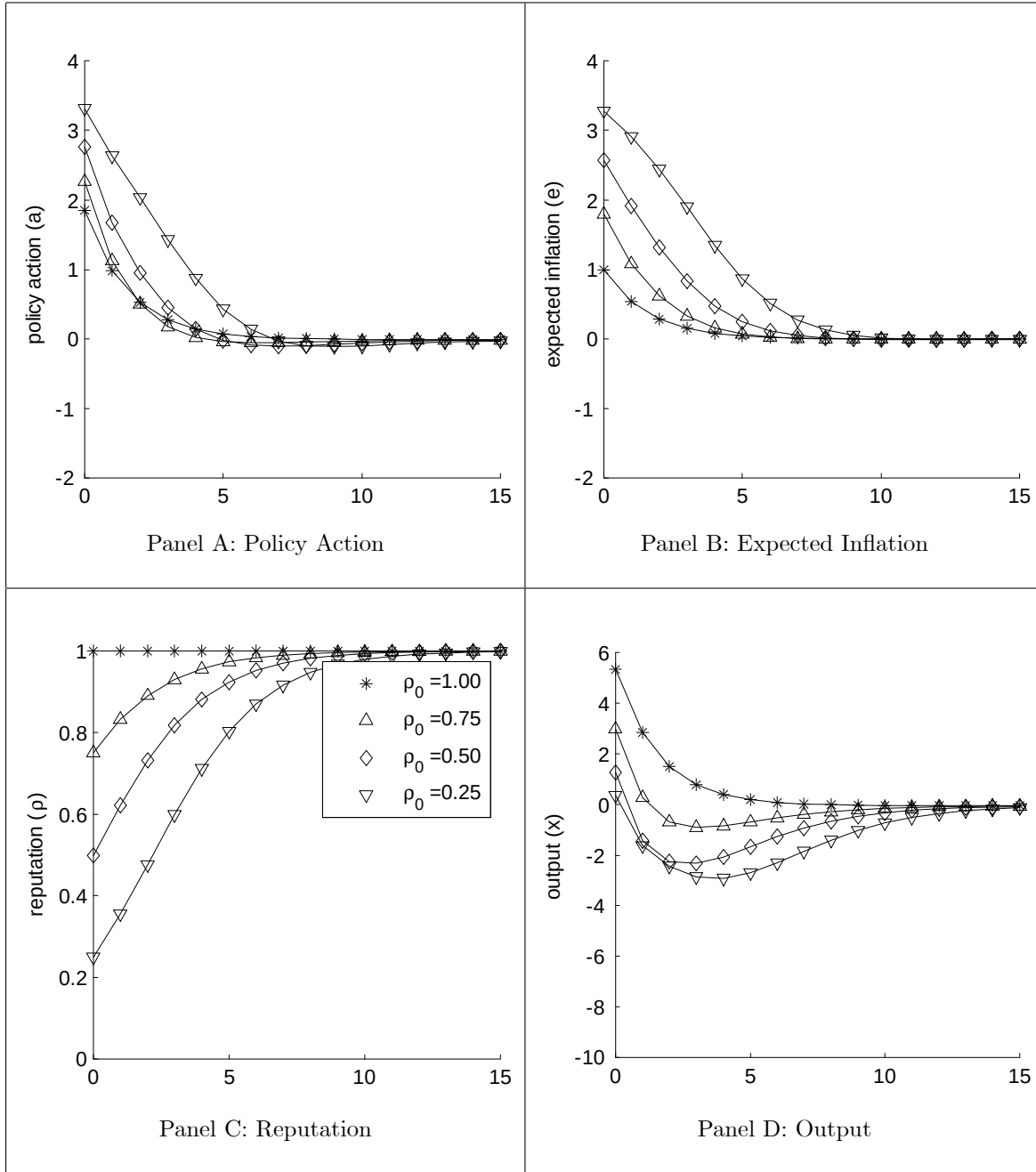


Figure 3.3: Startup dynamics without effect of policy action on learning. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in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

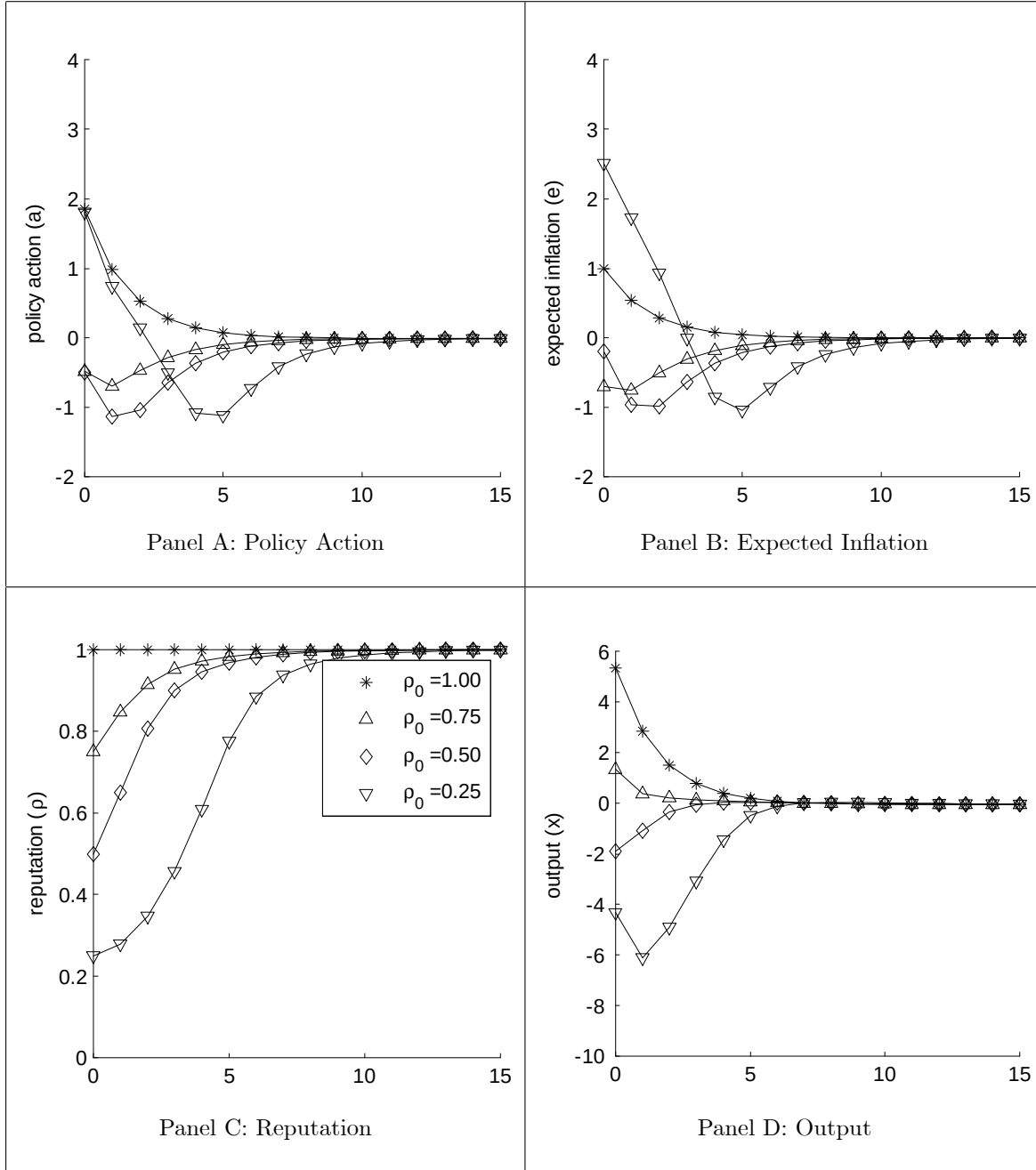


Figure 3.4: Startup dynamics with effect of policy action on learning, but no loss of leverage on expected inflation. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker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

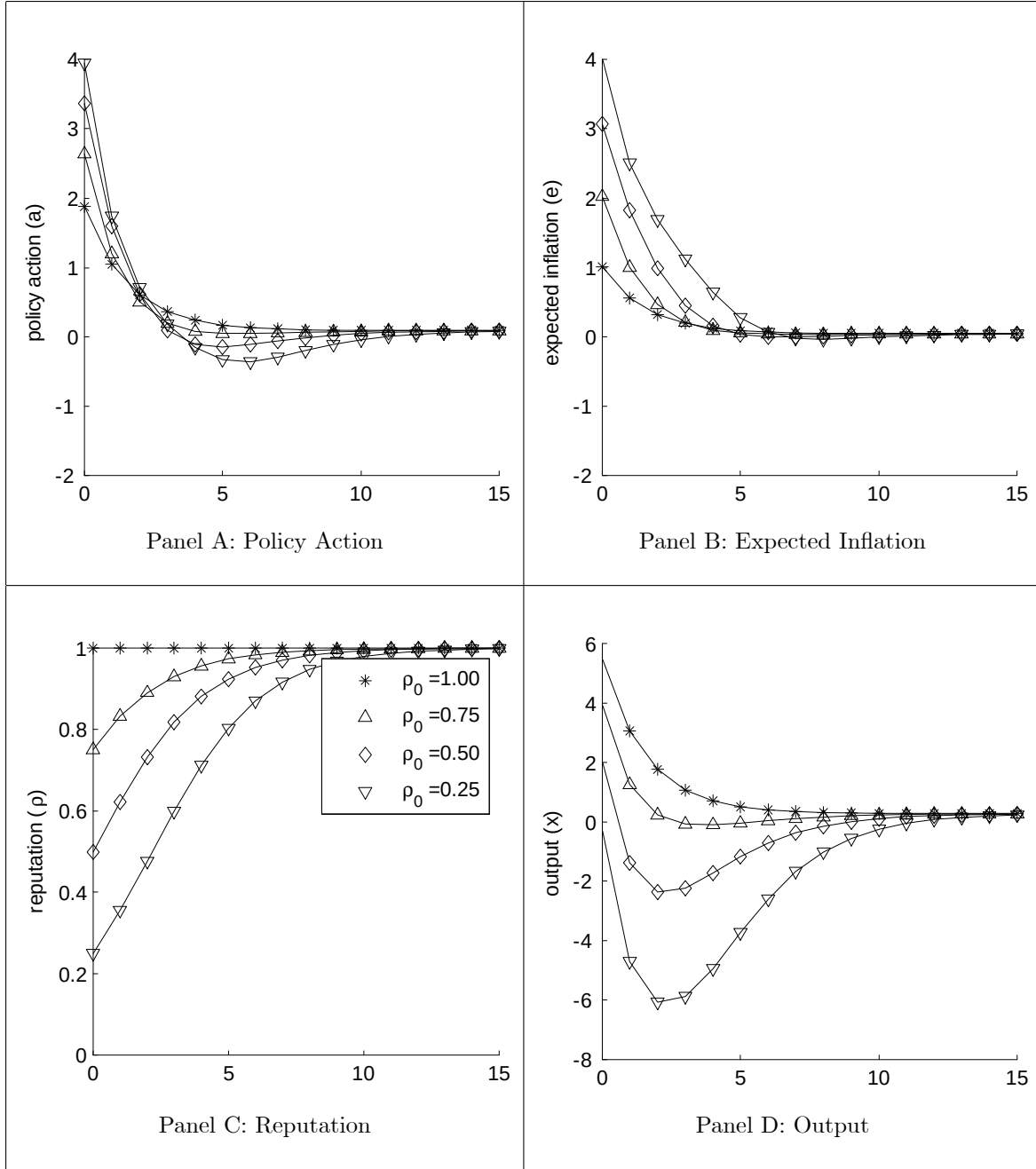


Figure 3.5: Startup dynamics with a tag-along alternative policymaker and endogenous reputation. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place.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

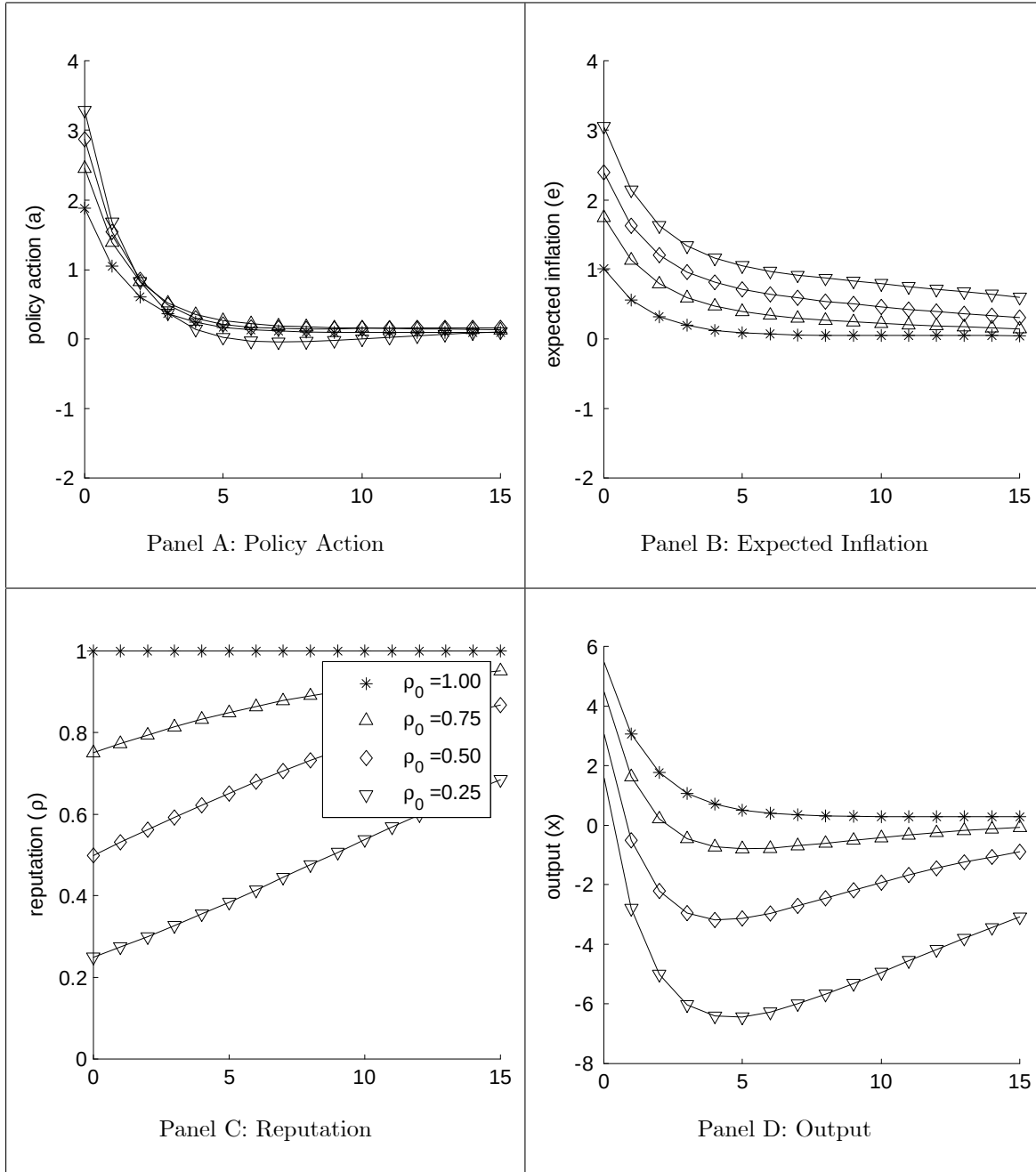


Figure 3.6: Startup dynamics with a tag-along alternative policymaker (with smaller inflation premium: half size of the inflation bias). Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

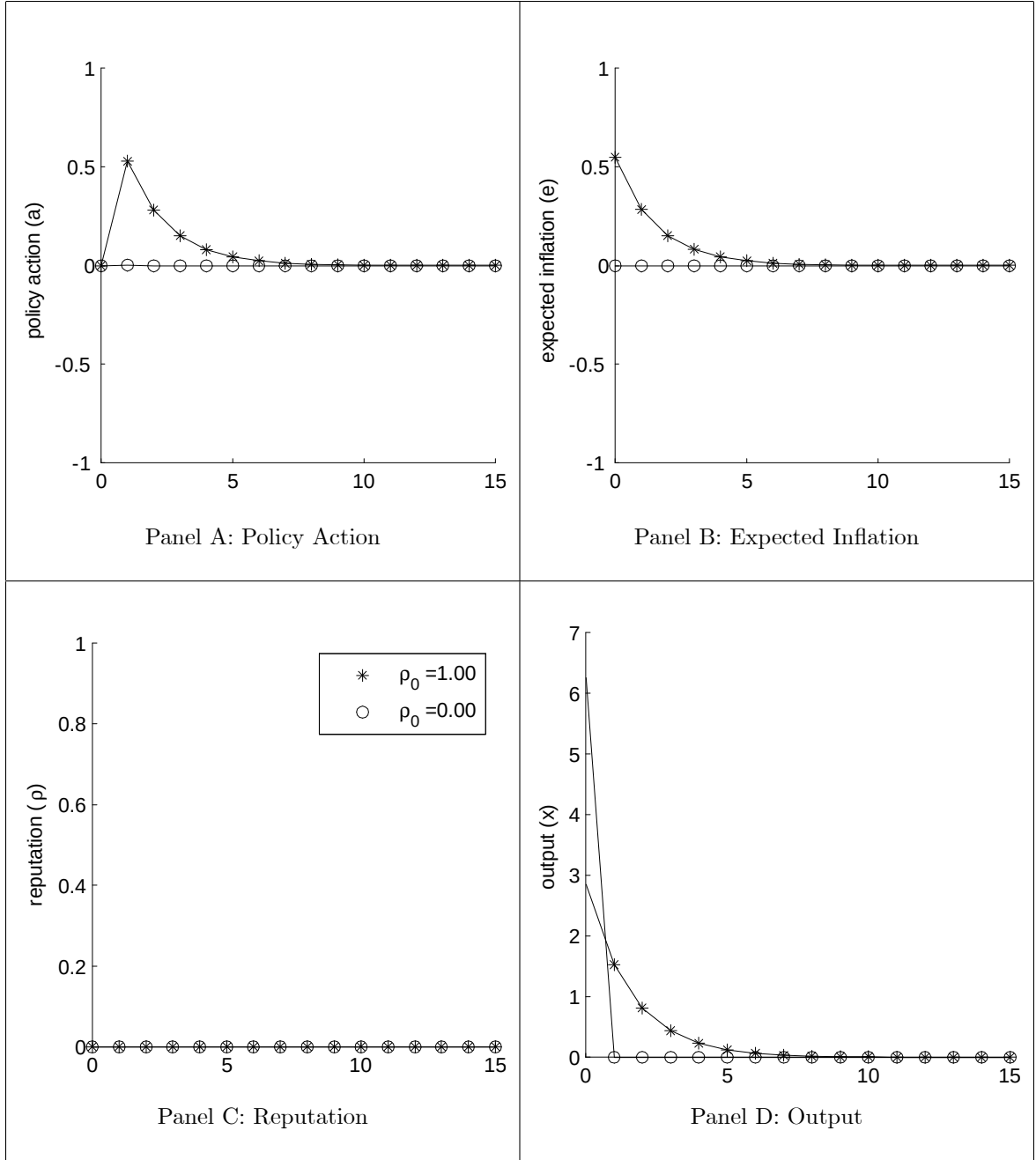


Figure 4.1: Impulse response to an implementation error (error is 1 percent in annual inflation rate or .0025 quaterly). Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

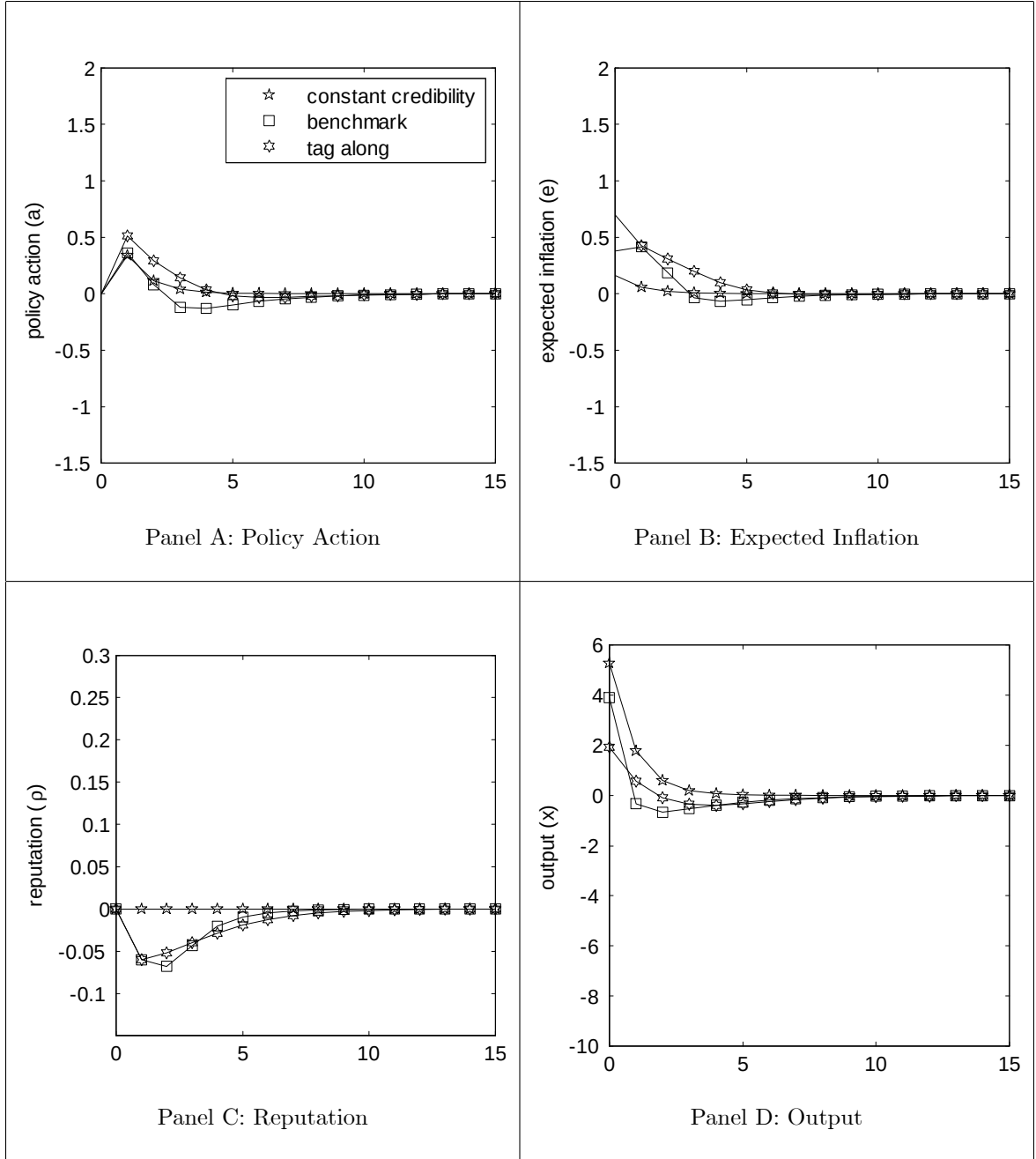


Figure 4.2: Impulse response to an implementation error from initial reputation of .5. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

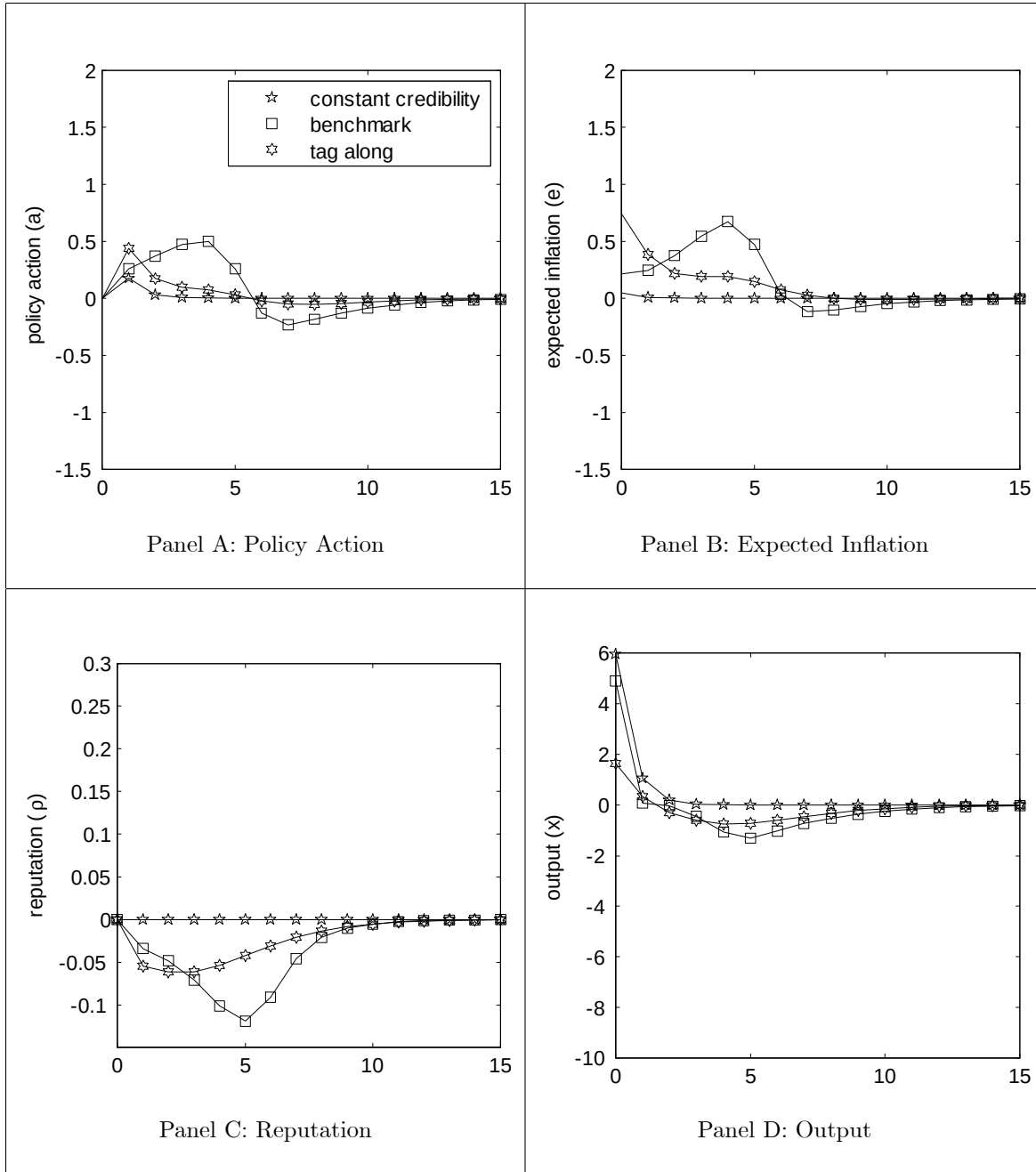


Figure 4.3: Impulse response to an implementation error from initial reputation of .25. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

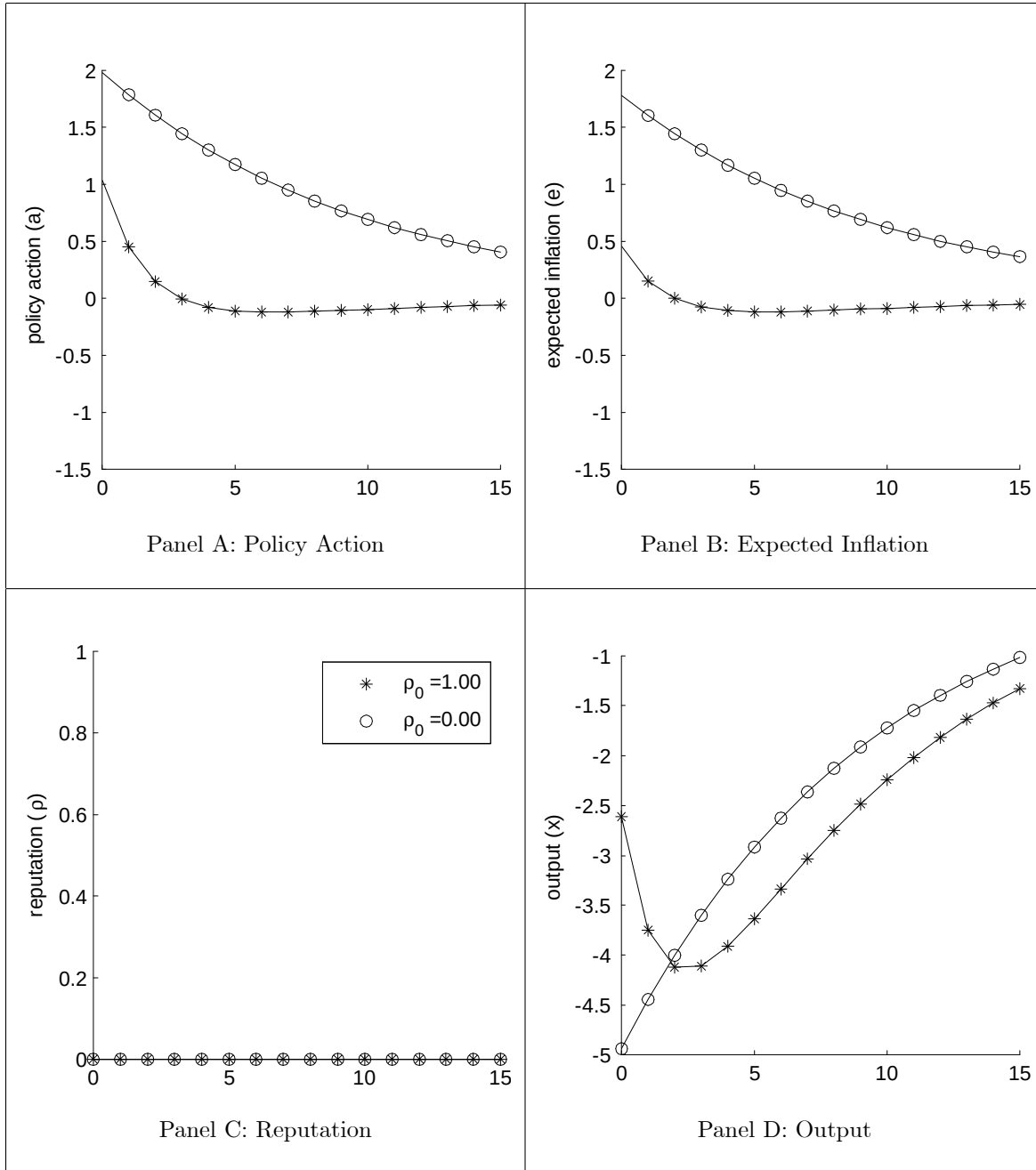


Figure 4.4: Impulse response to a persistent inflation shock (error is 1 percent in annual inflation rate or .0025 quaterly). Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

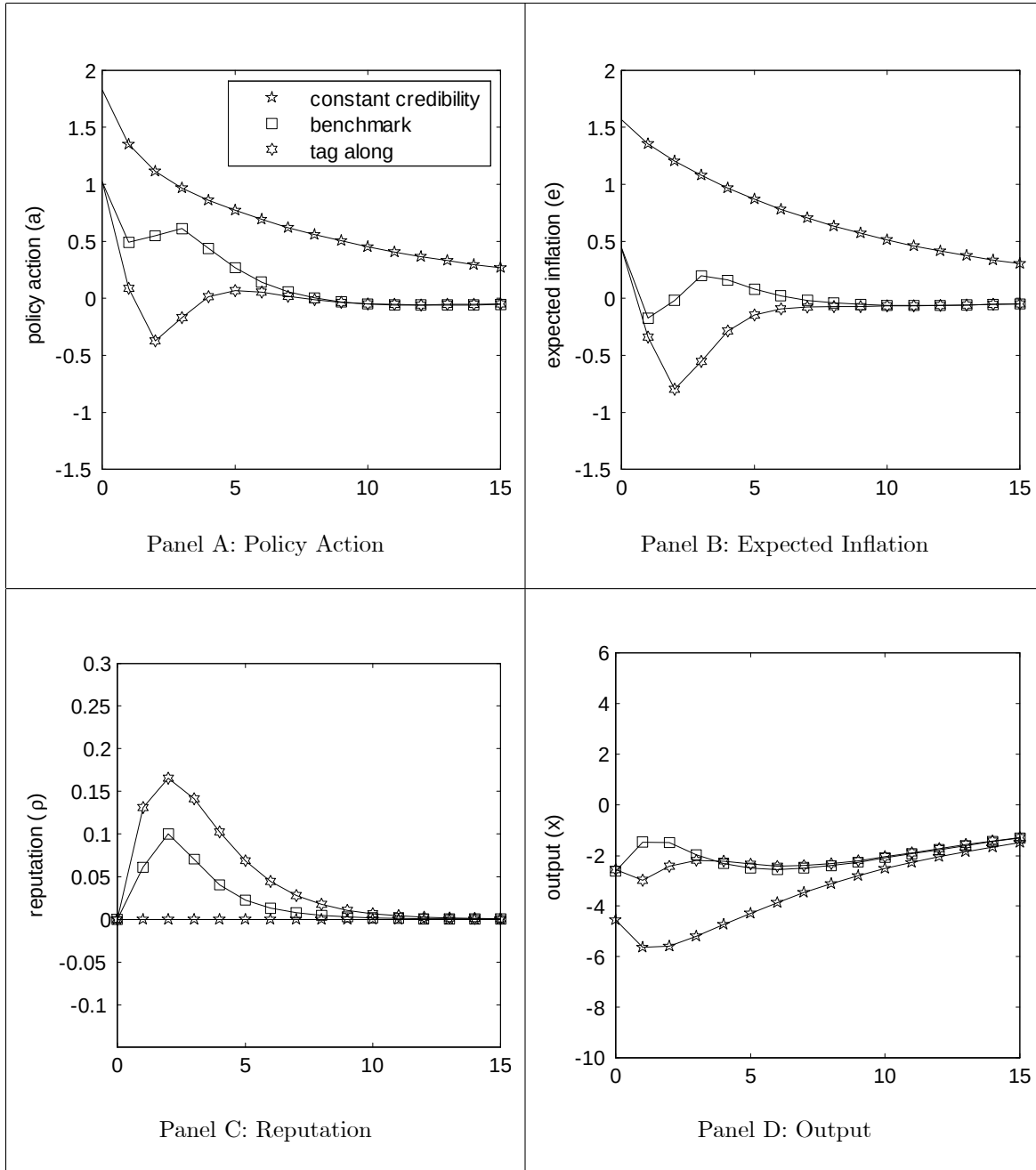


Figure 4.5: Impulse response to a persistent inflation shock from initial reputation of .5. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

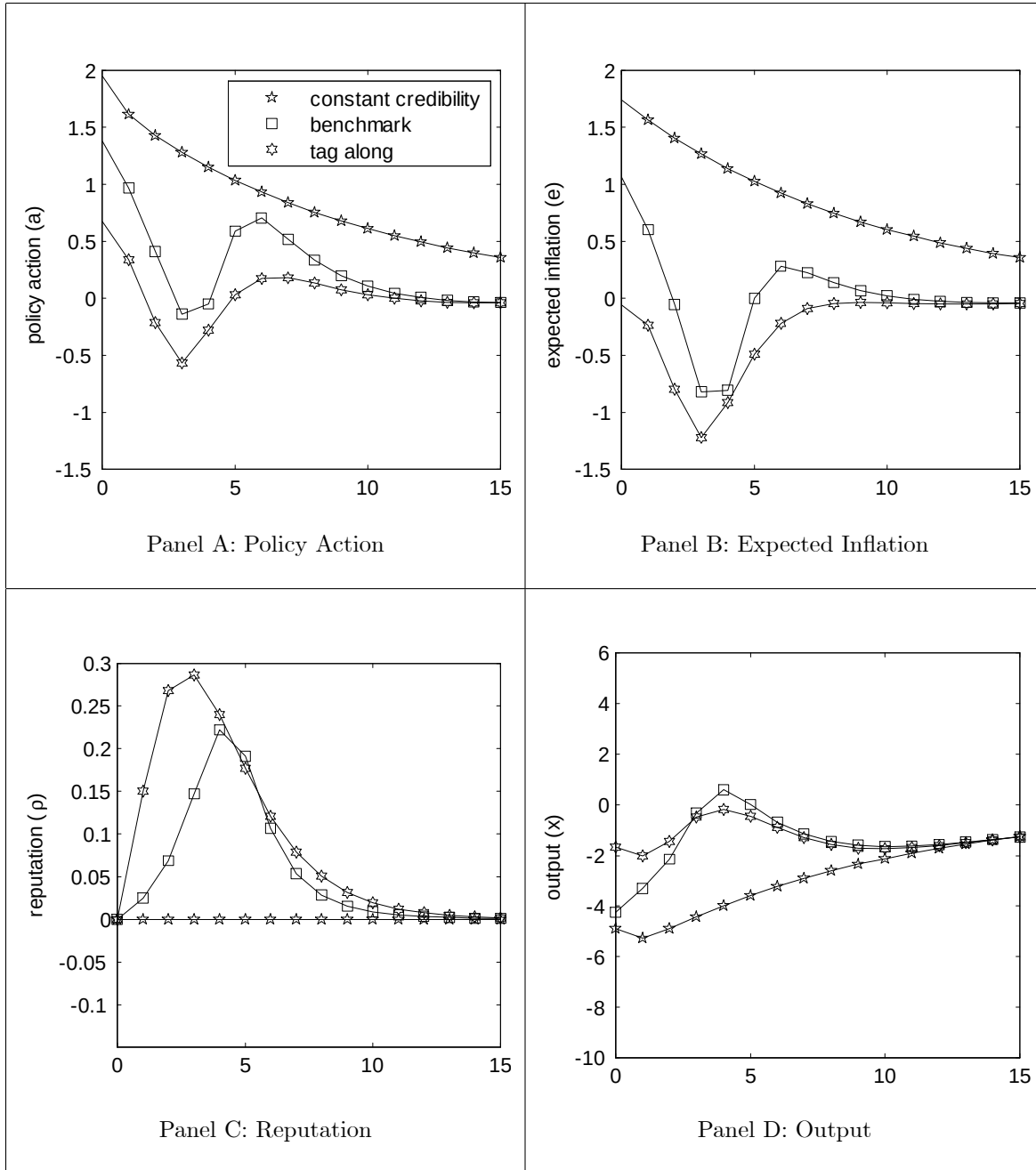


Figure 4.6: Impulse response to a persistent inflation shock from initial reputation of .25. Panel A: policy action (mean inflation) is percent per year. Panel B: private agents' expected inflation is percent per year. Panel C: reputation is the likelihood that a committed policymaker is in place. Panel D: output is in percent deviation from distorted steady state.

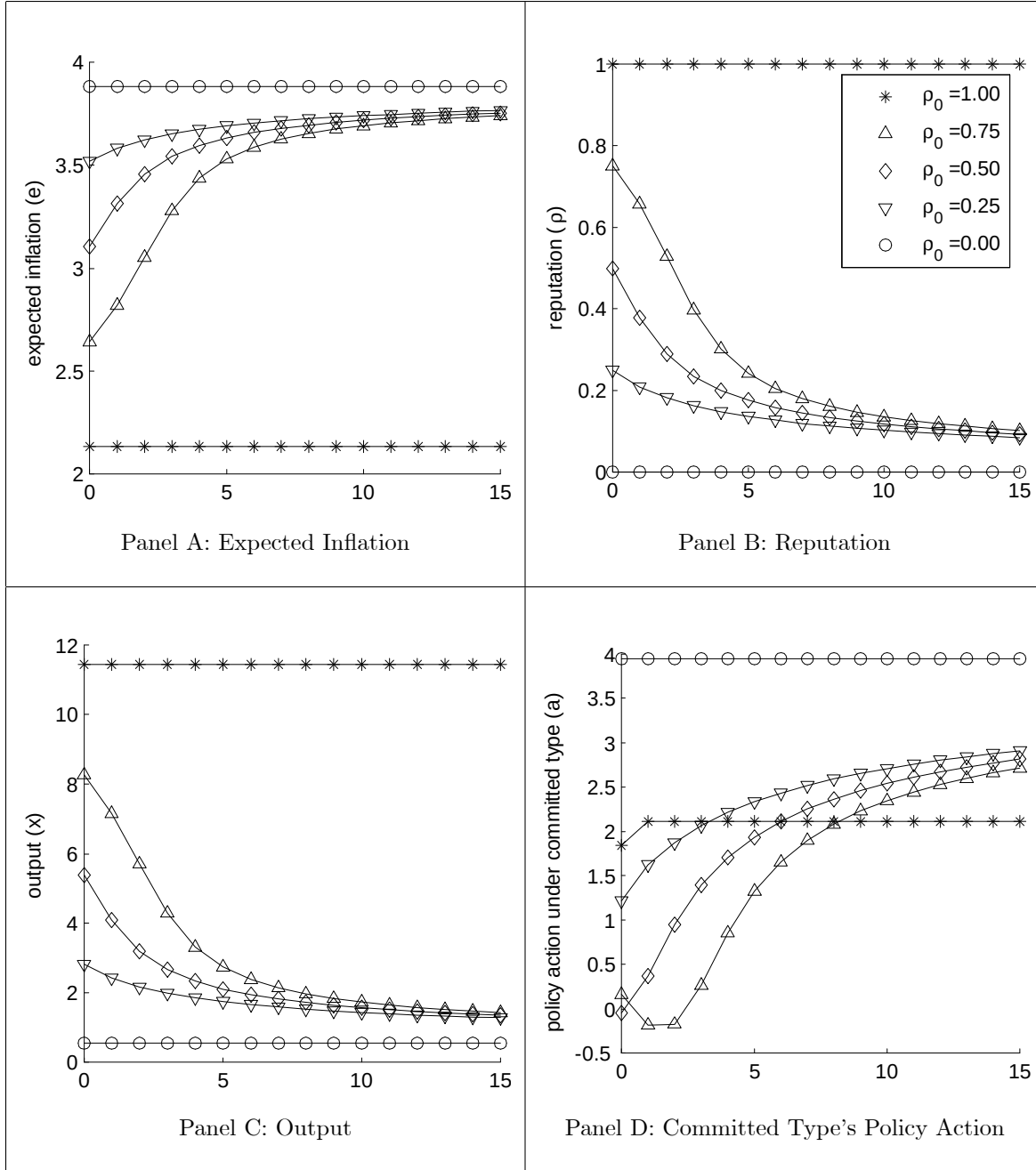
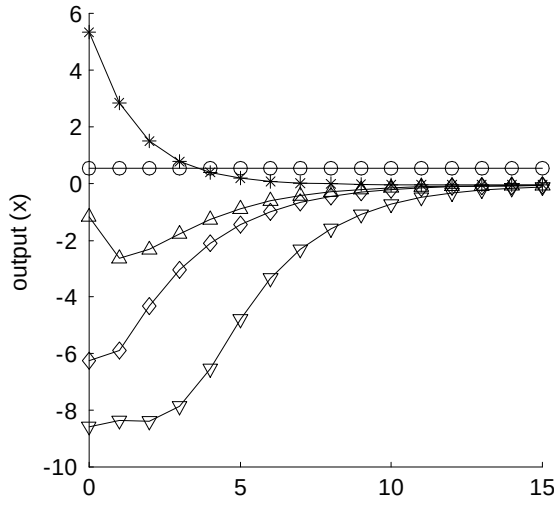
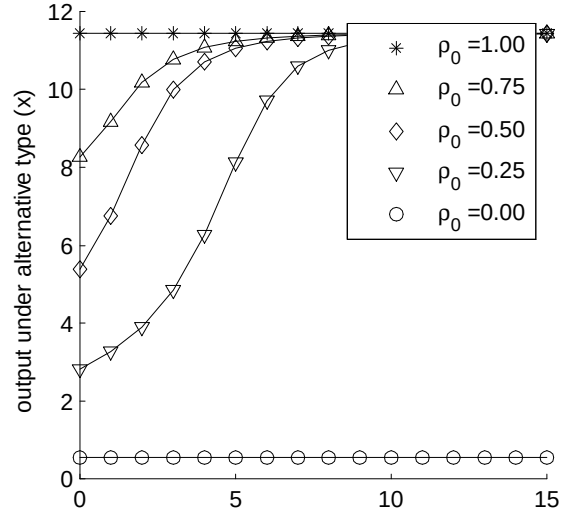


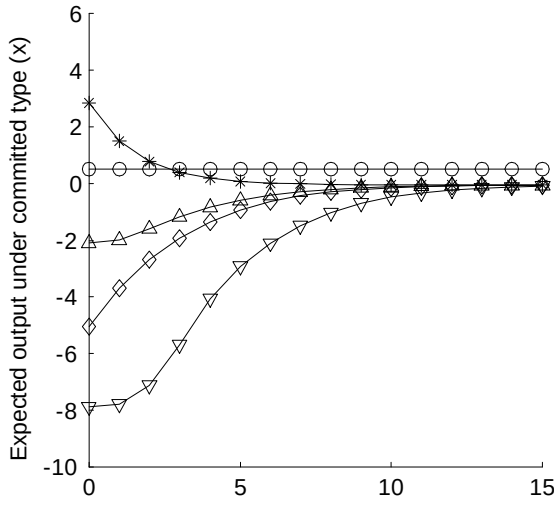
Figure 5.1: Startup dynamics with endogenous reputation when a benchmark alternative policymaker is in place. Panel A: private agents' expected inflation is percent per year. Panel B: reputation is the likelihood that a committed policymaker is in place. Panel C: output is in percent deviation from distorted steady state. Panel D: policy action (percent per year) if the current policymaker is the committed type.



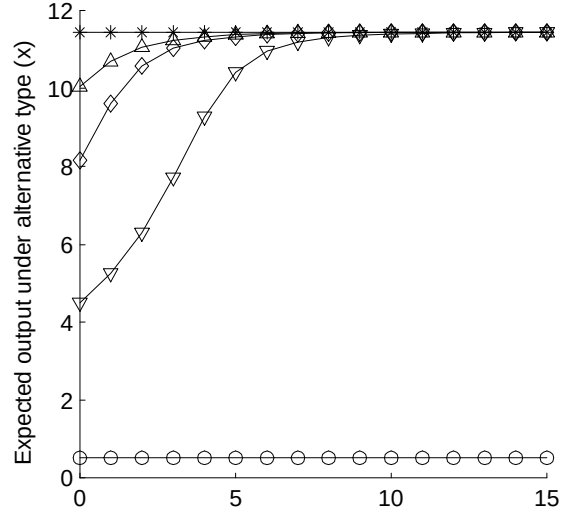
Panel A: Output under a committed type



Panel B: Output under an alternative type

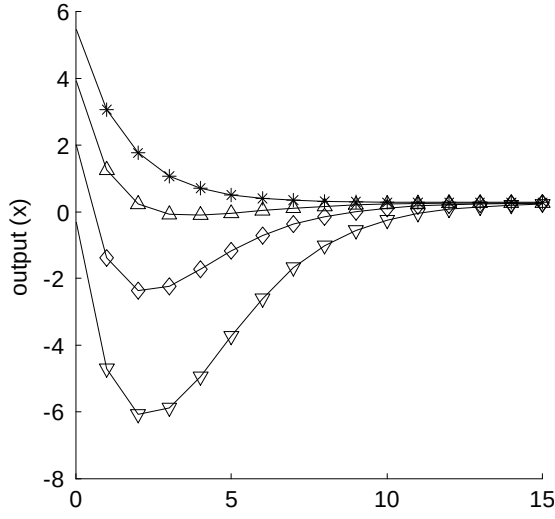


Panel C: Expected output under a committed type

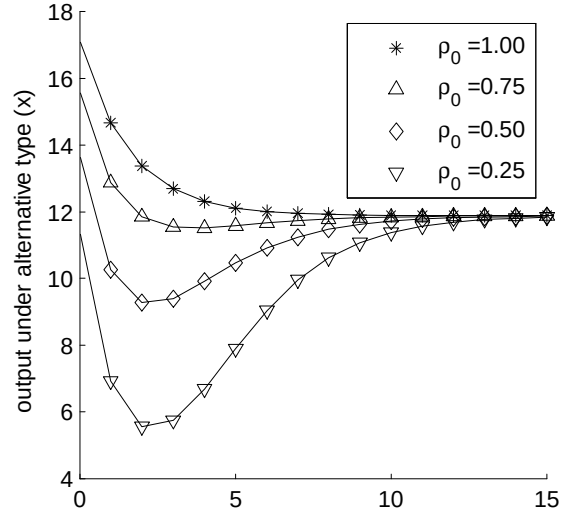


Panel D: Expected output under an alternative type

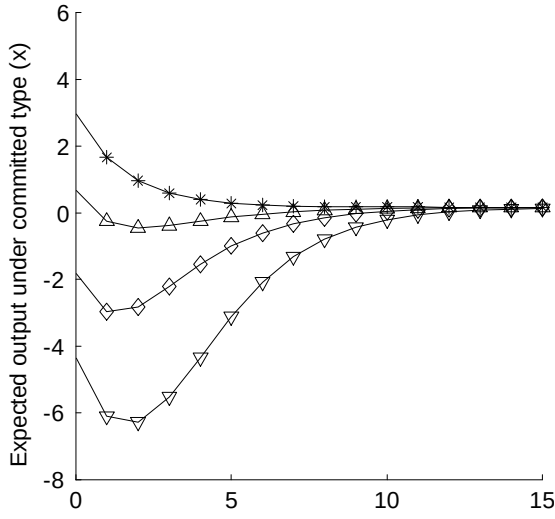
Figure 5.2: Output and expected output in startup dynamics with endogenous reputation and the alternative type being the benchmark case. Panel A: output when the committed policymaker is always in place. Panel B: output when the current policymaker is the alternative type. Panel C: expected output when the committed policymaker is always in place. Panel D: expected output when the next-period policymaker is the alternative type.



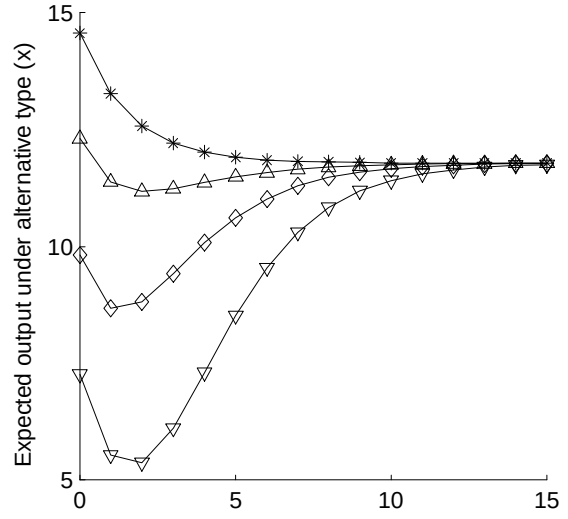
Panel A: Output under a committed type



Panel B: Output under an alternative type



Panel C: Expected output under a committed type



Panel D: Expected output under an alternative type

Figure 5.3: Output and expected output in startup dynamics with endogenous reputation and the alternative type being the tagalong case. Panel A: output when the committed policymaker is always in place. Panel B: output when the current policymaker is the alternative type. Panel C: expected output when the committed policymaker is always in place. Panel D: expected output when the next-period policymaker is the alternative type.

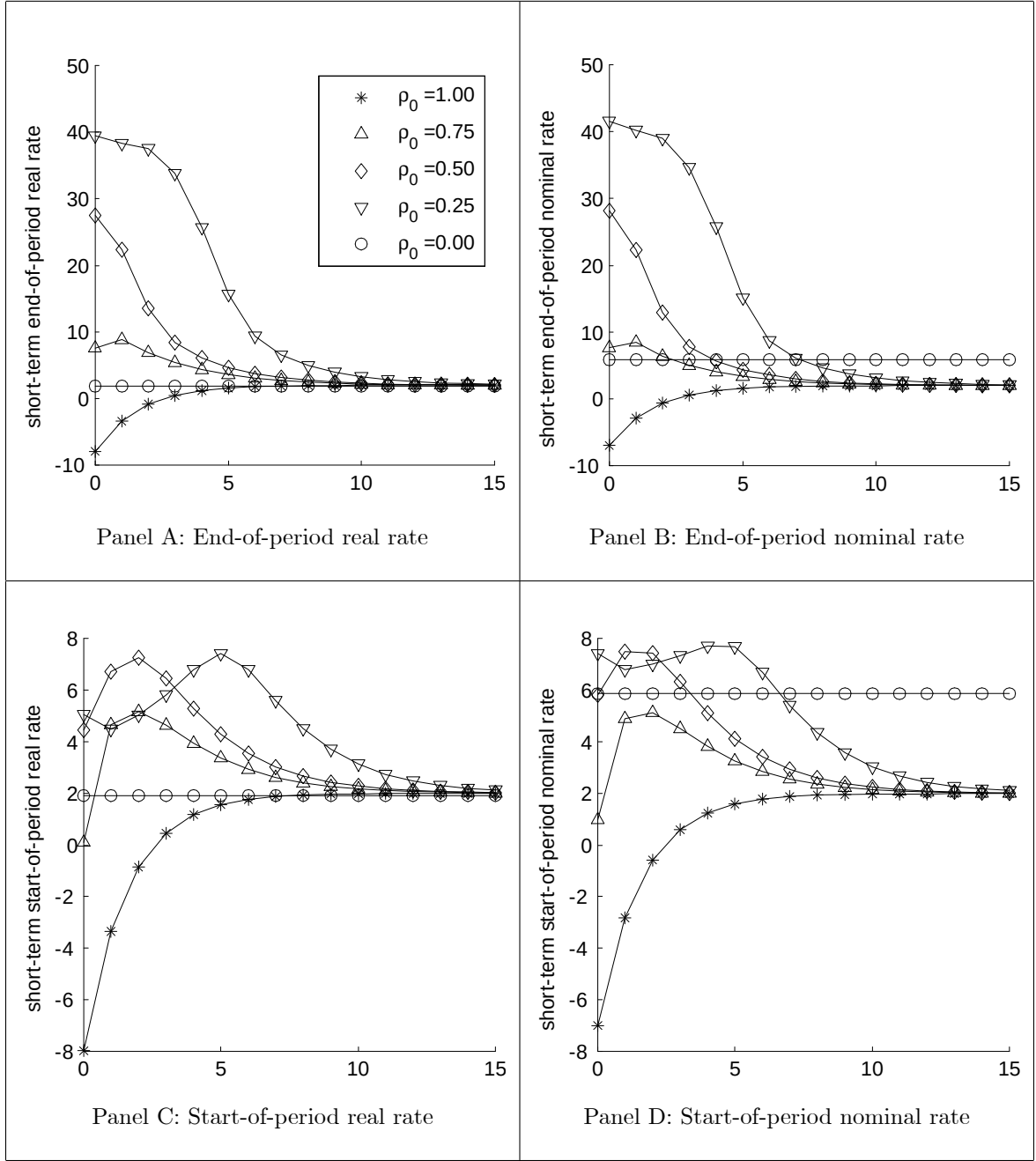


Figure 6.1: Short-term interest rates in startup dynamics with endogenous reputation and the alternative type being the benchmark case. Panel A: the annualized real interest rate in the end-of-period market. Panel B: the annualized nominal interest rate in the end-of-period market. Panel C: the annualized real interest rate in the start-of-period market. Panel D: the annualized nominal interest rate in the start-of-period market.

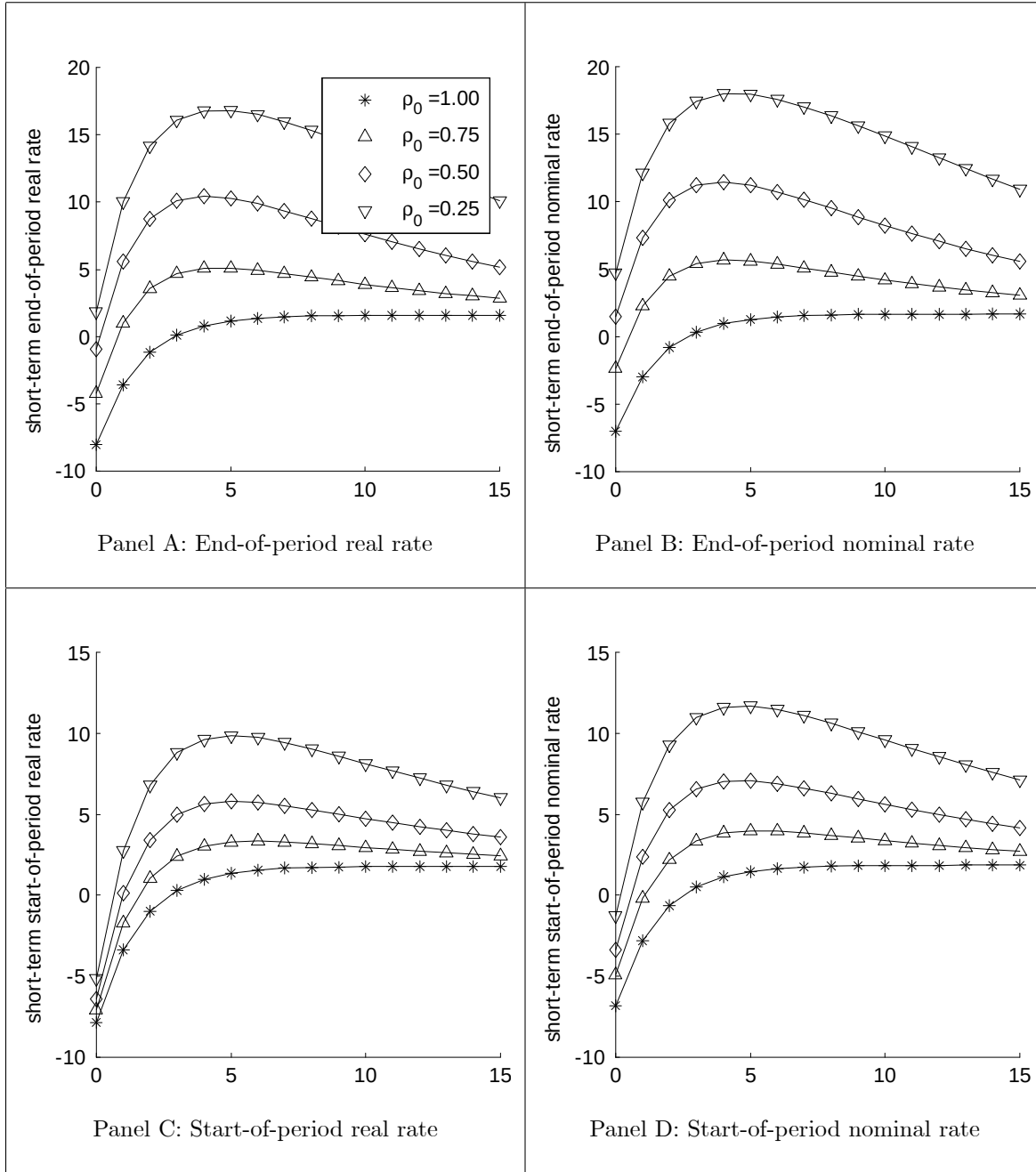


Figure 6.2: Short-term interest rates in startup dynamics with endogenous reputation and the alternative type being the tagalong case with the taglevel equal to half size of the inflation bias. Panel A: the annualized real interest rate in the end-of-period market. Panel B: the annualized nominal interest rate in the end-of-period market. Panel C: the annualized real interest rate in the start-of-period market. Panel D: the annualized nominal interest rate in the start-of-period market.