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Endogenous Monetary Policy Regime Change

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6.1 Introduction

Perhaps the most important advance in the monetary policy literature over the past twenty years is the explicit recognition that policy behavior is purposeful and responds endogenously to the state of the economy. Substantial progress has been made by research that examines how various monetary policy rules perform in dynamic stochastic general equilibrium (DSGE) models. A prominent example of such a rule is Taylor's (1993) rule, which has the central bank adjust the short-term nominal interest rate in response to fluctuations in inflation and some measure of output. Rare is the paper now that posits an exogenous process for money growth and claims to offer practical policy advice.

A substantial line of empirical work finds that Taylor's or other simple rules describing purposeful behavior display important time variation in the United States (Clarida, Gali, and Gertler 2000; Lubik and Schorfheide 2004; Favero and Monacelli 2005; and Sims and Zha 2006). Although particulars vary, a common theme across much of the empirical work on time variation in policy behavior is that changes in policy behavior are exogenous. Recent work embeds Markov switching processes for policy in DSGE models to interpret these empirical findings (Chung, Davig, and Leeper 2007; Davig and Leeper 2006, 2007).[1]

Because both the empirical and theoretical work on regime change treat the changes as exogenous, in an important sense the work is inconsistent with a central tenet underlying the Taylor rule: monetary policy behavior is purposeful and reacts systematically to changes in the macroeconomic environment. This chapter makes regime change endogenous, taking a step toward resolving this inconsistency.[2]

We distinguish two types of effects from exogenous disturbances.[3] *Direct effects* are the usual impacts of shocks that arise when agents place zero probability on regime change, corresponding to a fixed regime setup. *Expectations formation effects* arise whenever agents rational expectations of future regime change induce them to alter their expectations functions. Expectations formation effects are the difference between the impact of a shock when regime can change and the impact when regime is forever fixed.

The chapter shows that even very simple threshold-style methods for endogenizing regime changes can generate rich dynamics. The rich dynamics allow models that are linear, except for policy behavior, to display three features that connect to theoretical and empirical work on the impacts of shocks and to observations about how central banks act:

(1) Expectations formation effects generated by the possibility of regime change can be quantitatively important.

(2) Symmetric policy shocks can produce asymmetric effects.

(3) Preemptive policy behavior enhances the effectiveness of policy actions and delivers a quantitatively significant preemption dividend.

Endogenous switching shares the feature of quantitatively important expectations formation effects with exogenous switching. Davig and Leeper (2007) emphasize that if monetary policy switches exogenously between a more active and a less active reaction against inflation, agents' expectations and (therefore) the equilibrium outcomes always reflect the possibility that regime can change in the future. For example, expectations of a more active policy regime in the future diminish the impacts of shocks on current inflation, even when the current regime is less active.

Features (2) and (3) emerge with threshold endogenous switching, but are absent when regimes switch exogenously.

The second feature connects to a growing body of empirical evidence suggesting that typical macroeconomic shocks—such as oil prices, government spending, or nominal aggregate demand—have nonlinear effects on the economy (DeLong and Summers 1988; Cover 1992; Hooker and Knetter 1996; Hooker 2002; Ravn and Sola 2004; Choi and Devereux 2005; and Cologni and Manera 2006). Some asymmetric effects have been attributed to nonlinearities in the structure of the economy, such as real and nominal rigidities or changes in availability of financing over the business cycle (Akerlof and Yellen 1985; Ball and Romer 1990; Ball and Mankiw 1994; Bernanke and Gertler 1989, 1995; and Gertler 1992). Surico (2003, 2006) estimates central bank preferences and finds evidence of asymmetric loss functions at the Federal Reserve, at the European Central Bank, and (prior to monetary union) at the Bundesbank. Asymmetric policy preferences also underlie the opportunistic disinflation argument of Orphanides and Wilcox (2002). In this paper, all asymmetries arise from nonlinearities in the monetary policy process. Nonlinearities stem from discrete shifts in policy rules that are triggered by changes in the state of the economy.

The third feature arises from the emphasis central bankers place on the intrinsic forward looking nature of monetary policymaking (Bernanke 2004). Because of lags in when monetary policy actions affect real activity and inflation, central banks need to act before economic conditions deteriorate. A famous instance of forward looking policy occurred in 1994 when the Federal Reserve moved preemptively against increases in inflation that had only begun to show up in long-term bond yields. Goodfriend (2005) concludes that the preemptive strike was successful, as inflation remained low and long rates declined. Preemptive actions of this sort, while playing a central role in central bank thinking, have not been extensively modeled.[4]

This chapter applies a simple framework to implement endogenous monetary policy regime switching. When the central bank's target variables cross specified thresholds, the policy rule changes. One policy process posits that if at date $t - 1$ inflation is less than some threshold (π^*), policy obeys a usual Taylor rule at t; if inflation equals or exceeds π^*, the central bank implements a more aggressive stance at t.

On the surface, this setup may seem deterministic: given current inflation, the next period's regime is known exactly. But threshold switching makes forming rational expectations of regimes two or more periods in the future nontrivial, as they depend on the joint distribution of all the exogenous disturbances and on the structure of the economy. Because expectations of all future regimes are updated each period to incorporate news about realizations of shocks, threshold switching is a special case of a Markov process with endogenous time varying probabilities.

The examples of endogenous switching presented herein connect well to the behavior of inflation targeting central banks. Strict inflation targeting, which is far more prominent in academic discussions than in actual central banking, lines up with a threshold inflation rate (π^*) that triggers shifts in the policy rule. Flexible inflation targeting, which many central banks claim to pursue, involves more complex triggers that depend on both the threshold inflation rate and some measure of the output gap.

As applied to inflation targeting, endogenous switching departs from the usual linear-quadratic framework, by embedding the notion that the central bank has asymmetric preferences over its objectives, a possibility that Blinder (1997) discusses. If central bankers would prefer to be twenty-five basis points below their inflation target than above it, this can create a left skewed distribution of equilibrium inflation.

This chapter fits firmly into the literature that studies how DSGE models perform under various ad hoc policy rules, such as Taylor rules. That literature adopts the perspective that policy seeks second-best rules, rather than optimal rules, perhaps because the underlying exogenous shocks are not observed and uncertainty about the economy prevents them from being accurately inferred from observable time series. Second-best rules make policy choices a function of observables, like inflation and output, which the central bank aims to target.

Section 6.2 briefly compares various specifications of monetary policy—fixed regime, exogenous switching, and endogenous switching. Threshold switching in a flexible price model of inflation determination is used in sections 6.3 and 6.4 to illustrate the expectations formation effects and asymmetric distributions that endogenous switching generates. Section 6.4 details how agents form rational expectations, developing a time varying probabilities interpretation of regime change. Section 6.5 embeds threshold switching in the workhorse new Keynesian model and displays the impacts of aggregate supply shocks on inflation and output dynamics. The implications of a more plausible characterization of monetary policy behavior—in which both inflation and output thresholds determine the policy rule—are also laid out. Section 6.6 combines a dynamic threshold—involving past, current, and expected inflation—with a hybrid new Keynesian model to show how central banks might preemptively strike against inflation. In a calibrated version of the model, preemptive policy behavior is shown to enhance the effectiveness of policy actions, delivering a quantitatively significant preemption dividend. Section 6.7 concludes.

6.2 Quick Overview of Endogenous Regime Change

Monetary policy rules, such as Taylor's, are state-contingent in the sense that the policy interest rate adjusts to the state of the economy, where a fixed set of parameters govern the degree of adjustment. In an environment with endogenous regime switching, the policy rule is state-contingent in this conventional sense, but also in a broader sense. Namely, the parameters governing the degree of adjustment of the interest rate to economic variables are themselves a function of the economic state. For example, high rates of inflation may be particularly alarming to policy makers and trigger a systematically more aggressive response to inflation than in states with more benign rates of inflation.

To understand endogenous switching, it is useful to review fixed regime and exogenous switching specifications of policy behavior. Consider the simplified Taylor rule:

$$i_t = \kappa + \alpha\pi_t + \varepsilon_t, \tag{1}$$

where i_t is the short-term nominal interest rate controlled by the central bank, π_t is the inflation rate; and $\varepsilon_t \sim$ i.i.d. $N(0, \sigma^2)$ is an exogenous policy disturbance. This rule is state-contingent in the sense that the nominal interest rate adjusts to the inflation rate, which itself is a function of the underlying state vector describing the economy. However, the systematic component of policy (α) is constant. All deviations of i_t from $\kappa + \alpha\pi_t$ are folded into the exogenous shock.

An exogenously switching rule extends this framework to:

$$i_t = \kappa(S_t) + \alpha(S_t)\,\pi_t + \varepsilon_t, \tag{2}$$

where S_t is a discrete valued random variable that evolves stochastically and independently of the endogenous economic variables. Now monetary policy is a set of different rules of the form in equation (1), with a stochastic process governing the dynamic evolution of the rules. This makes the policy rule rather than just the policy instrument (the interest rate) state-contingent. In both equations (1) and (2), the parameters κ and α are given exogenously. The key difference between the two specifications is that equation (2) introduces a new source of disturbance to the economy (the process governing S_t) with important implications for expectations formation.

A simple example of endogenous switching makes the parameters of the monetary policy rule functions of lagged endogenous variables, as in:

$$i_t = \kappa(\pi_{t-1}) + \alpha(\pi_{t-1})\pi_t + \varepsilon_t, \tag{3}$$

where the monetary rule (again) is state-contingent, except that the state is now a lagged endogenous variable. As implemented in this paper, endogenous switching can make the functions $\kappa(\cdot)$ and $\alpha(\cdot)$ either deterministic or stochastic functions of π_{t-1}.

Evidently, there is no sharp conceptual distinction between endogenous regime change and nonlinear policy rules. The former is a discrete approximation to the latter. Discreteness may have some practical advantages to a central bank that seeks to communicate clearly about its policy actions: it is far easier to inform the public about two distinct policy stances—normal and tight, for instance—than about the continuum of responses implied by a response to inflation that is a continuous function of the inflation rate. Discreteness also serves a pedagogical purpose since it lends itself to sharper interpretations of the resulting equilibria.

6.3 The Monetary Policy Process

We assume a monetary policy process that permits the monetary authority to vary its response to contemporaneous inflation, depending on the state of the economy. For example, a monetary authority may respond systematically more aggressively when inflation exceeds a particular threshold, and less aggressively when inflation is below the threshold.[5]

When the threshold depends on lagged inflation, the monetary authority sets the nominal interest rate using the rule:[6]

$$i_t = \alpha_{S_t}\pi_t + \gamma_{S_t}x_t, \tag{4}$$

where x_t is a measure of the output gap. The coefficients on inflation and the output gap are functions of the inflation threshold (π^*), and lagged inflation:

$$\alpha_{S_t} = [1 - I(\pi_{t-1} \geq \pi^*)]\alpha_0 + I[\pi_{t-1} \geq \pi^*]\alpha_1, \tag{5}$$

$$\gamma_{S_t} = [1 - I(\pi_{t-1} \geq \pi^*)]\gamma_0 + I[\pi_{t-1} \geq \pi^*]\gamma_1, \tag{6}$$

where $I[\cdot]$ is the indicator function.[7] In sections 6.5 and 6.6, more sophisticated specifications that incorporate the output gap into the threshold and thresholds that depend on expected inflation are considered. In all cases, the monetary policy process incorporates a state-contingent systematic component of policy, so the interest rate rule used to implement policy varies with economic conditions. This represents the point of departure from simple instrument rules in which the systematic response of policy is invariant across time and states.

6.4 A Fisherian Model of Inflation

A simple model of inflation determination combines a standard Fisher equation with an interest rate rule for monetary policy. The Fisher equation can be derived from a perfectly competitive endowment economy with flexible prices and a one period nominal bond. A linearized asset pricing equation for the nominal bond is given by:

$$i_t = E_t\pi_{t+1} + E_t r_{t+1}, \tag{7}$$

where r_t denotes the real rate at t. The real rate evolves exogenously according to:

$$r_t = \rho r_{t-1} + v_t, \tag{8}$$

where $0 \leq \rho < 1$, and v_t is an independently and identically distributed (i.i.d.) random variable with a doubly truncated normal distribution with a mean of zero, variance of σ_v^2, and symmetric truncation points.

In the special fixed regime case where $\alpha_0 = \alpha_1 = \alpha > 1$ in equation (5), equilibrium inflation is uniquely determined by:

$$\pi_t = \frac{\rho}{\alpha - \rho} r_t. \tag{9}$$

As α increases, the effect of real rate shocks on inflation declines and monetary policy increasingly offsets the influence of real rate shocks.

6.4.1 *Threshold Switching Monetary Policy Regimes*

The monetary authority sets the nominal interest rate using

$$i_t = \begin{cases} \alpha_0\pi_t & \text{if } \pi_{t-1} < \pi^* \\ \alpha_1\pi_t & \text{if } \pi_{t-1} \geq \pi^* \end{cases}, \tag{10}$$

where and $\alpha_1 > \alpha_0 > 1$. Monetary policy is active in both regimes, and more active when $\pi_{t-1} \geq \pi^*$. We normalize the threshold to be $\pi^* = 0$. Monetary policy adopts a different rule with probability one every time lagged inflation crosses the inflation threshold. If lagged inflation does not cross the threshold, then the instrument rule switches with probability zero. We refer to this monetary policy as threshold switching, based on the time series literature on self-exciting threshold autoregressive models, in which lagged values of a variable can induce a change in regime (Ghaddar and Tong 1981). Monetary policy self-excites in this sense by influencing inflation, which itself determines future policy regimes.

In this model and all subsequent variants, private agents form rational expectations based on complete information regarding the policy making process. At date t they observe all current and past variables; to form expectations, they incorporate the effects that shocks have on the probability distribution over the policy rules. As section 6.4.4 explains, although at date t agents know regime at $t + 1$ with certainty, this does not imply that they know all future regimes because the sequence of regimes that is realized depends on the sequence of realizations of exogenous shocks (v_t) and the serial correlation properties of the real interest rate process.

6.4.2 *Equilibrium Characteristics*

Let Θ_t denote the state at date t. The solution to the model is a function that maps the minimum set of state variables ($\Theta_t = [r_t, \pi_{t-1}]$) into values for the endogenous variable (π_t).

All the models in this chapter are solved numerically using the monotone map algorithm, which finds a fixed point in decision rules. The algorithm uses a discretized state space, and requires a set of initial decision rules that reduce to a set of nonlinear expectational difference equations. Details of the numerical method appear in the Appendix.

With threshold regime change, a positive real rate shock raises inflation (as it does in a fixed regime), but the magnitude differs due to how agents formulate expectations of future inflation. With a fixed regime, agents know that monetary policy will respond symmetrically next period to real rate shocks regardless of the sign of the shock. Threshold regime switching induces agents to expect a stronger monetary policy response next period, whenever a positive real rate shock pushes inflation above its threshold.

To build intuition, it is helpful to consider a policy process that makes the two regimes very different: $\alpha_0 = 1.5$ and $\alpha_1 = 25$. This extreme example has policy adjusting the nominal rate very aggressively when inflation exceeds its threshold. In states where lagged inflation is below its threshold, the monetary authority still adjusts the nominal rate more than one-for-one with inflation, but to a degree more in line with conventional Taylor rule specifications.

In purely forward looking models with simple policy processes, like equation (10), regimes inherit their persistence from the real interest rate process. We make the real rate relatively serially correlated by setting $\rho = 0.9$.

Figure 6.1 reports the contemporaneous response surface for inflation as a function of the state—lagged inflation and the current real rate. States where lagged inflation exceeds its threshold trigger the more aggressive policy that almost completely offsets the effect of a real rate shock on inflation. This in evident in the figure from the nearly flat portion of the shaded surface when $\pi_{t-1} \geq 0$. States where lagged inflation is below the threshold trigger the less active policy, and real rate shocks have larger impacts on inflation, as shown in the left panels of the figure.

Turning to more plausible policies, consider the baseline policy $\alpha_0 = 1.5$ and $\alpha_1 = 3$. Figure 6.1 illustrates the response surface in comparison to the extreme example. The policy response, when inflation exceeds its threshold, is not as aggressive in the baseline policy, which allows real rates to have a larger impact on inflation. The figure also illustrates how expectations affect current inflation. When inflation is less than its threshold, the extreme and baseline policies both have $\alpha_0 = 1.5$. How-

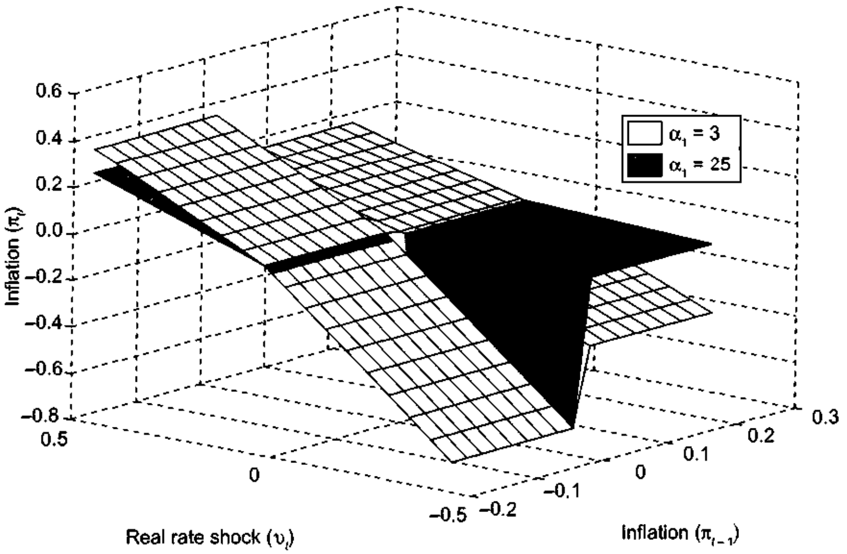

Figure 6.1
Contemporaneous response surface for inflation as a function of past inflation and current real rate shock in a Fisherian model.

Note: Less active regime is $\alpha_0 = 1.5$; more active regime is $\alpha_1 = 3$ (white surface) or $\alpha_1 = 25$ (shaded surface).

ever, the response surfaces differ because (in the extreme case) agents incorporate the fact that a large real rate shock will cause inflation to exceed its threshold in the future and trigger the more aggressive policy response. Thus (in the extreme case), positive real rate shocks have a smaller contemporaneous impact on inflation, even though both policies are responding with equal magnitude to current inflation. Much tighter future policy creates expectations formation effects that attenuate the increase in current inflation.

Figure 6.2 illustrates a slice of the response surface for given rates of lagged inflation. When lagged inflation is below its threshold (π_{t-1} = –0.2), the less active monetary policy is in place in the current period. A large positive real rate shock, however, can cause agents to expect more aggressive policy in the subsequent period. Consequently, the contemporaneous response of inflation has a kink at the point where a real rate shock triggers this shift in expectations. The positive real rate shock increases inflation, but by not as much as under the less active fixed regime policy, because expectations of future regimes affect the current

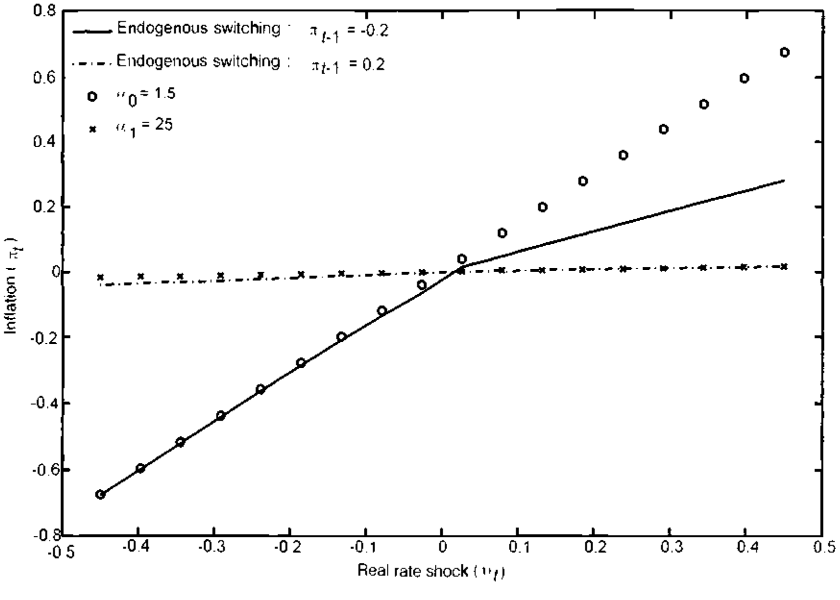

Figure 6.2

Contemporaneous inflation response to a real rate shock in a Fisherian model

Note: Threshold switching, π_{t-1} = –.2 (solid line) and π_{t-1} = .2 (dotted-dashed line) and fixed regime with less active (α_0 = 1.5) and more-active (α_1 = 3).

equilibrium. Expectations formation effects show up as the distance between the *o*'s (the fixed regime model with $\alpha = 1.5$) and the solid line (the switching model with $\alpha_0 = 1.5$ in place). This distance arises from the expectation of tighter policy next period, not from any difference between current policy stances.

Figure 6.3 corresponds to the impulse response evidence other studies have found for asymmetric impacts of macro shocks. The figure reports responses of inflation to one time negative and positive real rate shocks of equal magnitude. For reference, it also reports responses for fixed regimes that are less active (dashed lines) and more active (dotted-dashed lines). Monetary policy is initially in the more active regime. Following the positive shock, inflation rises and the more active regime stays in place. Since the more active policy is in place for both the positive and negative shocks in period one, the positive shock has a smaller absolute impact because agents expect to stay in the more active regime in the future, owing to the fact that persistence in the shock is likely to

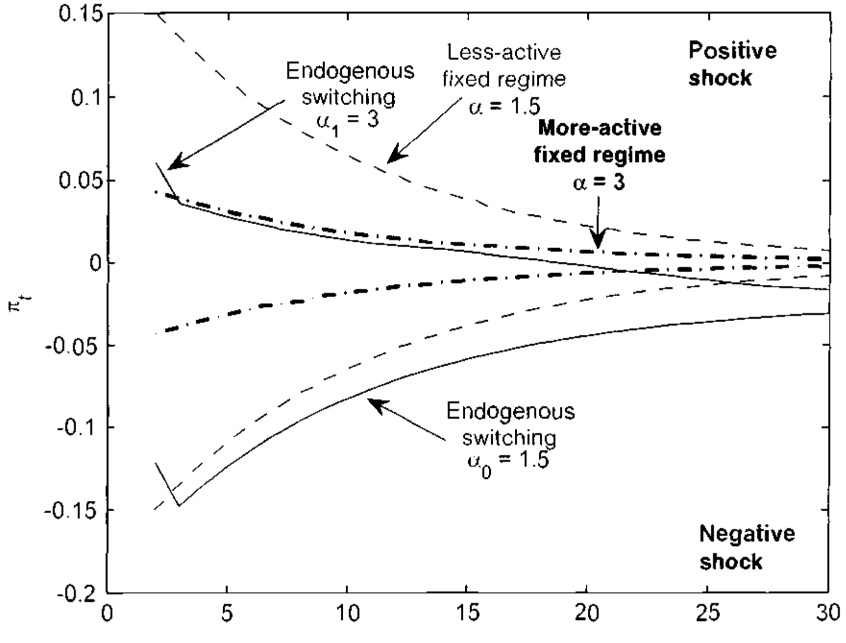

Figure 6.3
Responses of inflation to positive and negative real rate shocks in a Fisherian model
Note: Threshold switching (solid lines) and fixed regime less-active (dashed lines) and fixed regime more active (dotted-dashed lines).

keep inflation above threshold. The negative shock lowers inflation and causes policy to switch to the less active regime in period two; agents expectations adjust to reflect the greater likelihood that this regime stays in place in future periods. The change in expectations and less active policy do less to offset the negative shock, so inflation displays a more persistent deviation from its threshold than following a positive shock.

6.4.3 *Asymmetric Distributions*

As the impulse responses imply, threshold switching creates an asymmetric distribution of inflation. The fixed regime model with normal shocks implies a symmetric normal distribution. Under exogenous regime switching, the distribution for inflation is a mixture of the two conditional distributions in each regime, where each conditional distribution is normal. With endogenous switching, the distribution is skewed to reflect that low or negative inflation rates are more likely to occur than high inflation rates. For illustration, figure 6.4 reports three histograms for different values of the Taylor coefficient in the regime where inflation exceeds its threshold. A very aggressive response, $\alpha_1 = 25$ (top panel), produces a severely left skewed distribution whose tail extends into rates of inflation far below threshold. As α_1 declines, the degree of skewness also declines, but is still apparent in the case where $\alpha_1 = 3$. The skewness is eliminated as $\alpha_1 \rightarrow \alpha_0$.

Skewness arises from the expectations formation effects generated by the monetary policy process. The less active monetary policy is relatively accommodating of shocks in states where inflation is below its threshold and policy is anticipated to remain less active, so a negative shock to the real rate transmits through to inflation to a larger extent than when inflation is above its threshold. In contrast, when a shock raises inflation above its threshold and triggers an expected switch to the more active policy, the impacts on inflation are dampened.

6.4.4 *Time-Varying Probabilities of Switching*

Although the threshold switching setup employed implies that agents know the regime one period in advance, agents' expectations formation is nontrivial because they do not know all future regimes. The sequence of regimes that is realized depends on the sequences of exogenous shocks that are realized, and on the serial correlation properties of those shocks. This section describes (in detail) how agents form rational ex-

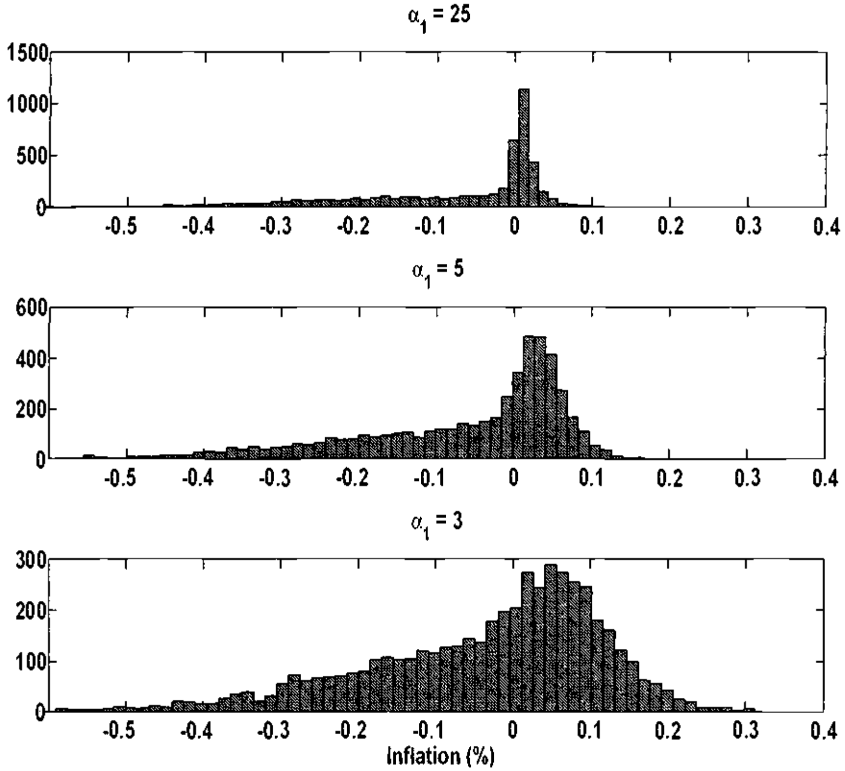

Figure 6.4
Distribution of inflation in a Fisherian model
Note: Threshold switching with less active regime $\alpha_0 = 1.5$ and various settings of more-active regime.

pectations in this environment, clarifying the nature of expectations formation in the face of threshold switching of policy regimes.

In a state where the real rate shock is zero and inflation equals its threshold, agents know that the more aggressive regime will be in place next period because $\pi_{t-1} \geq 0$. Forming expectations two periods ahead requires agents to compute the probability that (in the following period) a shock will hit, which causes inflation to fall and policy authorities to adopt the less active regime.

The probability of future regimes can be characterized precisely. The solution for inflation as a function of the minimum set of state variables, $\Theta_t = (r_t, \pi_{t-1})$, can be expressed as:

$$\pi_t = h^{\pi}(r_t, \pi_{t-1}). \qquad (11)$$

The smallest v_t, which is the innovation in the process for the real rate shock, necessary to induce $S_{t+1} = 1$ (the state with more aggressive policy) is given by the solution to:

$$\min_{v_t} h^{\pi}[\rho r_{t-1} + v_t, h^{\pi}(r_{t-1}, \pi_{t-2})] \text{s.t. } \pi_t \geq 0.$$

The objective function is $h^{\pi}(r_t, \pi_{t-1})$, which is increasing in v_t, so the minimization problem simply finds the smallest innovation to the shock process that creates non negative inflation at time t. The probability of $S_{t+1} = 1$ is then:

$$\Pr[S_{t+1} = 1 \mid \Theta_{t-1}] = \int_{v_t^*}^{\bar{v}} \phi(v; \sigma_v^2) dv, \qquad (12)$$

where $\bar{v}$ is the positive truncation point, v_t^* is the solution to the minimization problem, and Θ_{t-1} includes all information at time $t - 1$ (which includes π_{t-1} and, therefore, S_t). The integral in equation (12) gives the probability of realizing a shock at t, $v_t \geq v_t^*$, whose value is sufficiently large to induce $S_{t+1} = 1$.

To build intuition, consider an example. The economy is in its deterministic steady-state at date $t - 2$, so $\pi_{t-2} = r_{t-2} = 0$, which puts policy in the more active regime ($S_{t-1} = 1$). Given the realization of v_{t-1}, regime at t is known, and Pr $[S_t = 1 \mid \Theta_{t-1}]$ is a step function: if $v_{t-1} \geq 0$, then $\pi_{t-1} > 0$, and $\Pr[S_t = 1 \mid \Theta_{t-1}] = 1$; whereas if $v_{t-1} < 0$, then $\pi_{t-1} < 0$, and $\Pr[S_t = 1 \mid \Theta_{t-1}] = 0$.

Regime at $t + 1$, however, is not so easily deduced. Because the real rate shock is positively serially correlated, $v_{t-1} < 0$ creates low inflation at $t - 1$ and at future dates. To trigger a regime change, the innovation at t must be both positive and large enough to offset the persistent negative effects on inflation of the previous shock. Evidently, the smaller the negative shock at $t - 1$, the more likely it is that the shock at t will push inflation over the threshold and make $S_{t+1} = 1$.

The minimization problem for this example becomes:

$$\min_{v_t} h^{\pi}[\rho v_{t-1} + v_t, h^{\pi}(v_{t-1}, 0)] \text{s.t. } \pi_t \geq 0.$$

Two parameters are critical to the solution of this problem—ρ, which governs the degree of serial correlation of the real interest rate, and α_1, the strength of the policy reaction to inflation in the more active regime.[8] Figure 6.5 plots $\Pr[S_{t+1} \mid \Theta_{t-1}]$ as a function of the innovation to the real rate at $t - 1$, for various degrees of serial correlation (ρ). The figure is

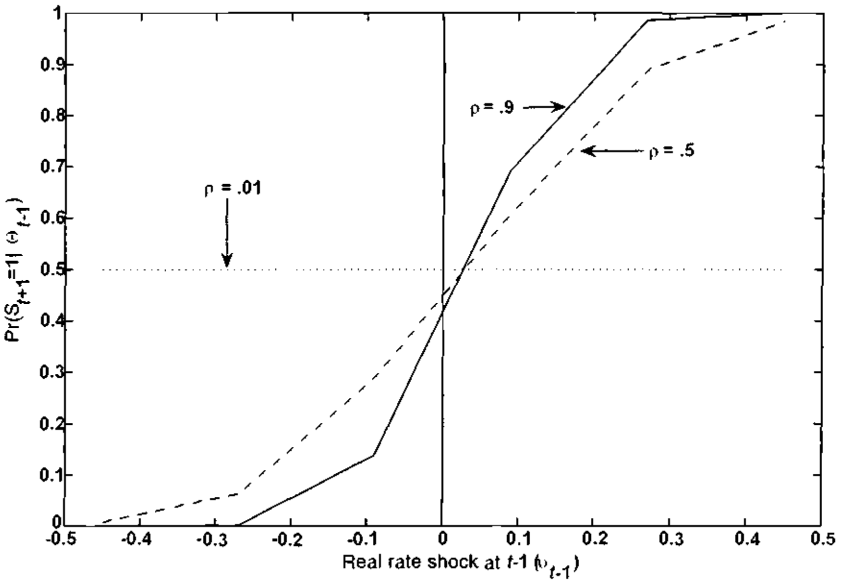

Figure 6.5
Probability of $S_{t+1} = 1$

Note: Conditional on information at $t - 1$, $\Theta_{t-1} = (r_{t-1}, \pi_{t-2})$, as function of the real interest rate shock at $t - 1$, for various values of the serial correlation of the exogenous shock ρ. Drawn for $\alpha_0 = 1.5$ and $\alpha_1 = 3$.

drawn for $\alpha_0 = 1.5$ and $\alpha_1 = 3$. When the shock is (i.i.d., $\rho = 0$), regime is also i.i.d., changing each time a shock of a different sign is realized.[9] Regardless of the realization of v_{t-1}, there is a fifty-fifty chance of either the less active or the more active regime at $t + 1$ (dotted line). As the real rate becomes more persistent, if $v_{t-1} > 0$, the probability of switching to the less active regime declines because it is less likely that a shock at t will be sufficiently large and negative to offset the serially correlated increase in inflation from the date $t - 1$ positive shock. As the figure shows, for a given realization of v_{t-1}, the probability of staying in the more active regime rises monotonically with ρ. This is a manifestation of the expectations formation effects.

Expectations formation effects also increase with the strength of the monetary policy reaction to inflation in the more active regime. Figure 6.6 plots $\Pr[S_{t+1} | \Theta_{t-1}]$ as a function of the innovation to the real rate at $t - 1$, for various values of α_1 (the Taylor coefficient in the more active regime). The figure is drawn for $\alpha_0 = 1.5$ and $\rho = 0.9$. For a given real-

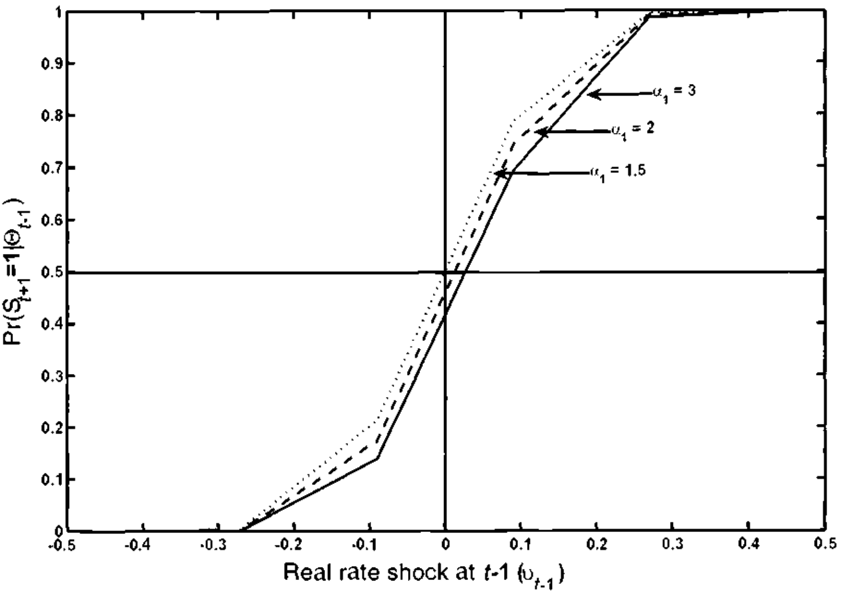

Figure 6.6
Probability of $S_{t+1} = 1$
Note: Conditional on information at $t-1$, $\Theta_{t-1} = (r_{t-1}, \pi_{t-2})$, as function of the real interest rate shock at $t-1$, for various values of the Taylor parameter in the more active regime, a_1. Drawn for $a_0 = 1.5$ and $\rho = .9$.

ization of $v_{t-1} > 0$, the probability of staying in the more active regime from period t to period $t+1$ falls monotonically with α_1. Put differently, as α_1 rises, monetary policy offsets real rate shocks to a larger extent in the more active regime and raises the probability that future inflation will be below threshold (triggering the less active policy). Consequently, larger shocks are required to keep the probability of switching to the more active regime constant as α_1 rises. The presence of a more active regime, and a threshold rule for switching to it, changes expectations so that the economy spends more time in the less active regime. These expectations formation effects underlie the asymmetric distribution of inflation in figure 6.4.

In general, a state where inflation is above threshold and the current real rate shock is positive results in agents placing little probability mass on the adoption of the less active regime anytime in the near future. In such a state, expectations closely resemble those in a fixed regime setting, where agents place zero probability on a change.

6.5 Threshold Switching in a New Keynesian Model

We now turn to assess the implications of endogenous regime switching within a conventional new Keynesian model, as described in Woodford (2003). The log-linear consumption Euler equation and aggregate supply relations are:

$$x_t = E_t x_{t+1} - \sigma^{-1}(i_t - E_t \pi_{t+1}) + g_t, \tag{13}$$

$$\pi_t = \beta E_t \pi_{t+1} + \kappa x_t + u_t, \tag{14}$$

where aggregate demand and supply shocks follow:

$$g_t = \rho_g g_{t-1} + \varepsilon_{gt} \tag{15}$$

$$u_t = \rho_u u_{t-1} + \varepsilon_{ut} \tag{16}$$

with $0 \leq \rho_g < 1$ and $0 \leq \rho_u < 1$. Innovations to the exogenous shocks have doubly truncated normal distributions with mean of zero, and variances σ_g^2 and σ_u^2. For illustrative purposes, we use a conventional calibration: $\beta = 0.99, \omega = 0.66, \sigma = 1, \rho_g = \rho_u = 0.9, \sigma_g^2 = \sigma_u^2 = 0.025$, where $1 - \omega$ is the fraction of firms that reset their price each period, following Calvo (1983) pricing. This calibration implies $\kappa = 0.18$.

6.5.1 Monetary Policy Specification

This section focuses on a monetary policy process where the current regime depends on lagged inflation, and policy responds to contemporaneous inflation, as in the Fisherian model. The policy rule, in terms of deviations from the deterministic steady-state, is:

$$i_t = \alpha_{S_t} \pi_t. \tag{17}$$

The coefficient on inflation is a function of the inflation threshold and lagged inflation.

$$\alpha_{S_t} = [1 - I(\pi_{t-1} \geq \pi^*)]\alpha_0 + I[\pi_{t-1} \geq \pi^*]\alpha_1,$$

with $\alpha_1 > \alpha_0 > 1$.

6.5.2 Supply Shocks

Figure 6.7 reports the contemporaneous response of inflation to supply shocks at t for two values of lagged inflation—one that is below the

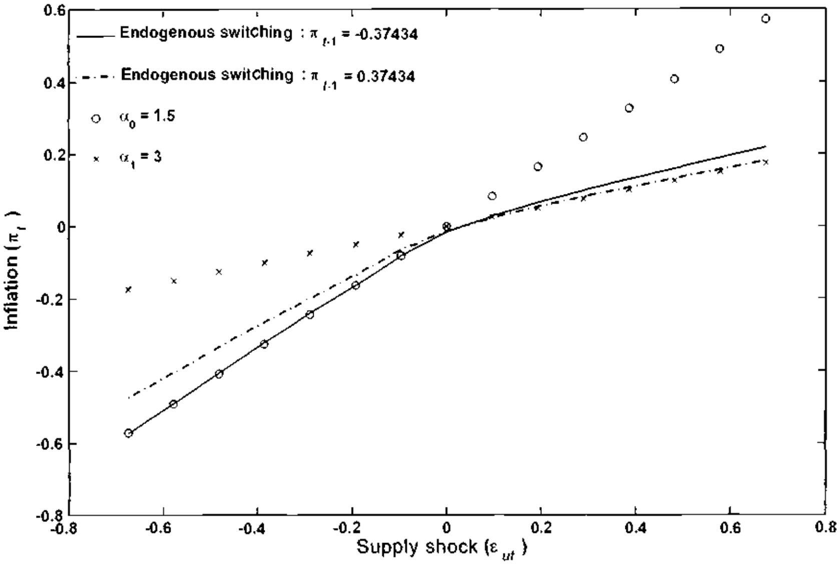

Figure 6.7
Contemporaneous response of inflation to supply shocks in the new Keynesian model
Note: Threshold switching and fixed regime with less active (a_0 = 1.5) and more-active (a_1 = 3).

threshold and triggers less active policy at t (solid line), and one that exceeds the threshold and triggers the more active regime at t (dotted-dashed line). For contrast, the figure also plots the contemporaneous impacts of supply shocks on inflation when regime is fixed and less active (α_0 = 1.5, o's) and when it is more active (α_1 = 3, x's). The inflation threshold is set to zero, which is consistent with the steady-state inflation rate around which the model equations are linearized.

The figure highlights the expectations formation effects that affect the equilibrium. Consider the solid line, which corresponds to below threshold π_{t-1}, so policy is in the less-active regime at t. Positive supply shocks raise inflation but only slightly more than they would in a fixed, more active regime, and raise it much less than in a fixed, less active regime. The certainty that regime at $t + 1$ will switch to being more active dampens inflation even when the prevailing regime is less active, so the expectations formation effects are given by the vertical distance between the o's and the solid line. Expectations formation effects arising from the probability of switching back to less active policy in periods $t + k$, for $k > 1$, make the solid line lie above the x's—the more active fixed regime.[10]

Parallel reasoning applies to negative supply shocks. When inflation is above threshold at $t - 1$ (dotted-dashed line), so policy is more active at t, the deflationary shock triggers the expectation of less active policy at $t + 1$: inflation falls by more than it would if more active policy were permanent (vertical distance between dashed lines and x's). But inflation also falls by less than it would under a fixed, less active regime because of the probability regime will switch back to a more active stance in subsequent periods.

In this purely forward-looking model, expectations formation effects are quantitatively significant. If agents know that policy next period will be more (less) active, then the current equilibrium will more closely mimic the equilibrium with a fixed more- (less-) active policy, even when current policy is less (more) active.

6.5.3 *Asymmetric Equilibrium Distributions*

Asymmetry arising from endogenously switching policy is apparent in impulse responses. Figure 6.8 reports the responses for output, inflation, and the nominal rate to one standard deviation positive and negative

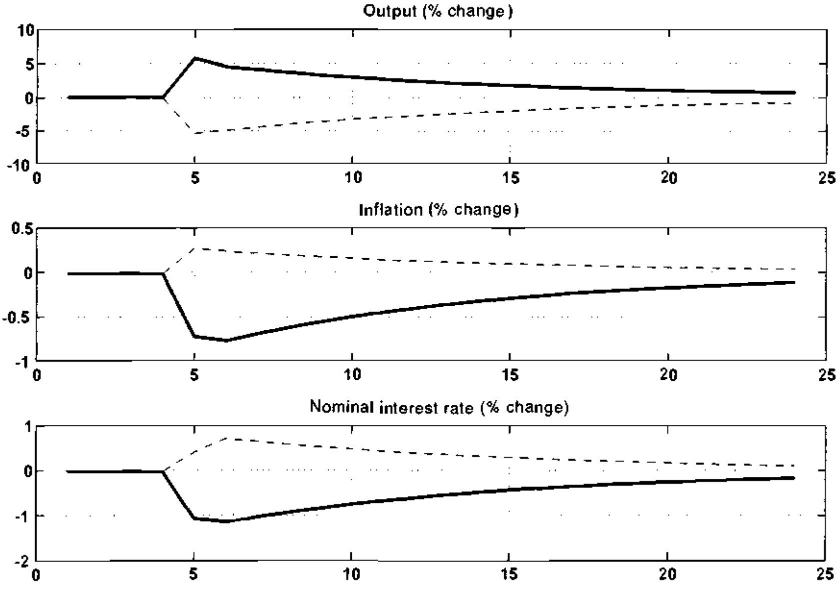

Figure 6.8
Responses to positive and negative supply shocks in the new Keynesian model with threshold switching

supply shocks, starting from the more active regime initially. In the figure, the positive supply shock's impact on inflation is offset by monetary policy to a larger extent than is the negative supply shock. Positive shocks raise inflation and cause agents to increase the probability they attach to monetary policy remaining in the more active regime.

The negative supply shock produces a kink in the period following the initial shock. Expectations prior to the supply shock were placing roughly equal weight on future monetary regimes. Following the negative supply shock, agents revise their expectations, placing more weight on the less active monetary regime since the probability of inflation exceeding its threshold in the near future is relatively low. The effects of the revisions of expectations towards the more accommodating monetary regime are realized the period following the shock, causing a further drop in inflation and the kink that is apparent in the figure.

6.5.4 *Output and Inflation Thresholds*

Flexible inflation targeting central banks operate under a legislative mandate that specifies multiple objectives—price stability, stable growth, high employment, safe payments systems, and so forth. The Swedish central bank, for example, is instructed that "without prejudice to the price stability target, [it] should furthermore support the goals of general economic policy with a view to maintaining a sustainable level of growth and high rate of employment" (Sveriges Riksbank 2006, 2).

Flexible inflation targeting can be modeled by extending the preceding analysis to make the switch in policy rules depend on both inflation and output gap thresholds. The second threshold builds additional nonlinearity into the response surfaces for inflation and output. The monetary rule is given by:

$$i_t = \begin{cases} \alpha_0 \pi_t & \text{if } \pi_{t-1} < \pi^* \text{ and } x_{t-1} \geq 0 \\ \alpha_0 \pi_t + \gamma_0 x_t & \text{if } \pi_{t-1} < \pi^* \text{ and } x_{t-1} < 0 , \\ \alpha_1 \pi_t & \text{if } \pi_{t-1} \geq \pi^* \end{cases} \quad (18)$$

where $\gamma_0 > 0$ and $\alpha_1 > \alpha_0 > 1$. If inflation exceeds its threshold, regardless of the level of output, the central bank responds aggressively to inflation and essentially disregards output gap fluctuations (the "without prejudice to price stability" mandate). In states when inflation is below its threshold, the monetary authority turns to output stabilization objectives, while still responding actively to inflation (the "maintain growth" mandate). When the output gap is negative, the monetary authority responds to the output gap by lowering rates; when it's positive, the monetary authority does not respond to output fluctuations, reflecting a preference to let the boom continue, so long as inflation remains contained.

Figure 6.9 plots two response surfaces for inflation against lagged inflation and the contemporaneous supply shock. The shaded response surface is for states with $x_{t-1} < 0$, and the solid white surface is for states with $x_{t-1} \geq 0$. In the state with the negative output gap, the monetary authority adjusts the nominal rate to stabilize output (a positive coefficient on the output gap term in the policy rule). In states when inflation is below its threshold, the shaded surface indicates that policy does not aggressively offset supply shocks to stabilize inflation; this appears in the steep portion of the surface in this state. When inflation exceeds its threshold, the two response surfaces connect since the rules in this state are the same. If inflation is below its threshold and output is above its threshold, then the monetary authority does less to stabilize output. In

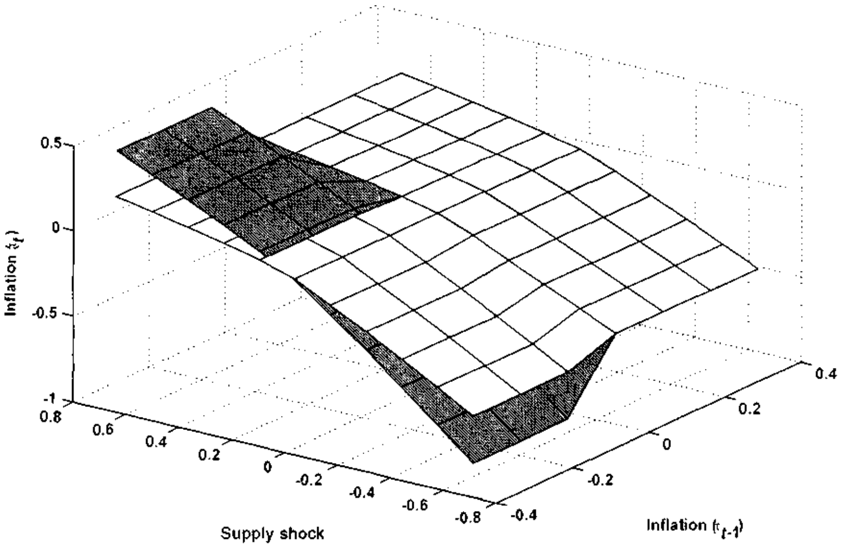

Figure 6.9
Contemporaneous response surface for inflation as function of past inflation and current supply shock

Note: Inflation and output gap thresholds. White surface is states with $x_{t-1} \geq 0$; shaded surface is states with $x_{t-1} < 0$.

this state a positive supply shock drives up inflation and drives down output, but the monetary authority responds only to inflation, not output. In contrast to the case when output is below threshold, a positive supply shock drives up inflation and drives output down further; but there is a more aggressive interest rate response that stabilizes output.

6.6 Threshold Switching and the Preemption Dividend

Central banks aim to strike preemptively by aggressively increasing interest rates in response to latent future inflation. Federal Reserve behavior in 1994 is an example of such a strike: rapid increases in long-term bond yields were viewed as reflecting expectations of higher future inflation, despite relatively docile contemporaneous inflation. Goodfriend (2005) describes this episode as an inflation scare, and argues it is an illustration of a successful preemptive strike against inflation, based on subsequent realizations of low inflation, the flattening out of the yield curve, and the decline in survey measures of expected inflation through 1995 (Clark 1996).

Establishing and maintaining the central bank's credibility as an inflation fighter is central to Goodfriend's argument that preemption is good policy. By demonstrating its willingness to act boldly to combat inflation, even before it shows up in headline measures, a central bank can anchor inflation expectations. As Bernanke (2004) emphasizes, preemption was a hallmark of Federal Reserve policy under Alan Greenspan.

While it is possible to model preemptive actions in fixed regime models as an intervention on exogenous shocks to the monetary policy rule, as Leeper and Zha (2003) do, it is difficult to see how that approach can have the lasting effects on expectation formation that Goodfriend emphasizes lie at the heart of combating inflation scares. Interventions on shocks can shift conditional expectations, but they cannot affect expectations functions; they generate direct effects, but no expectations formation effects. Discrete shifts in policy rules that affect expectations functions seem to be an integral part of Goodfriend's study.

To model a preemptive strike, we need an environment in which expected inflation can rise in response to a shock. The canonical new Keynesian model (of the previous sections) produces rapid adjustments to shocks, so any persistence in output and inflation arises from serial correlation in the exogenous shock process. The hybrid new Keynesian model (Clarida, Gali, and Gertler 2000, Christiano, Eichenbaum, and Evans 2005) introduces backward looking elements to behavior that permit inflation and output to exhibit the hump-shaped dynamics often found in VAR studies. When shocks generate a steadily increasing path of inflation, the monetary authority is presented with the opportunity to respond more aggressively than normal to rising forecasts of inflation.

The Phillips curve from the hybrid new Keynesian model is:

$$\pi_t = (1 - \omega_\pi)\pi_{t-1} + \omega_\pi E_t\pi_{t+1} + \lambda x_t + u_t, \tag{19}$$

where π_{t-1} enters due to the assumption that firms that cannot reoptimize their pricing decisions, simply index their nominal prices to past inflation. The consumption Euler equation is:

$$x_t = (1 - \omega_x)x_{t-1} + \omega_x E_t x_{t+1} - \sigma^{-1}(R_t - E_t\pi_{t+1}) + g_t. \tag{20}$$

The shocks (u_t and g_t) are i.i.d., have means of zero, and obey a doubly truncated normal distribution. The parameter ω_x is an index of internal habit formation.

A preemptive strike calls for a different rule in certain states. States that imply high and rising current inflation, coupled with rising expected inflation, trigger a more aggressive monetary policy rule. Let the vector of current and lagged endogenous variables at t be denoted by $\xi_t = (\pi_t, x_t, \pi_{t-1}, x_{t-1})$, and define the policy process to be:

$$i_t = \begin{cases} \alpha_0\pi_t & \xi_t \notin \Upsilon_t \\ \alpha_1\pi_t & \xi_t \in \Upsilon_t \end{cases}, \tag{21}$$

where $\alpha_1 > \alpha_0 > 1$. The inflation-scare state (Υ_t) that generates a preemptive policy switch is defined as:

$$\Upsilon_t = (\xi_t \mid \pi_t \geq 0, \pi_t > \pi_{t-1}, E_t\pi_{t+1} > \pi_t). \tag{22}$$

The conditional expectation of inflation that enters the preemptive state (Υ_t) is both the central bank's and the private sector's rational expectation formed conditional on policy specification (21) and (22), and the economic structure in (19) and (20), along with the distribution of the shocks.

Expressions (21) and (22) combine a simple feedback rule with forward looking threshold switching criteria to produce a forecast based policy process. In practice, most central banks follow forecast based policies (Bernanke 2004; and Svensson 2005), so the specification in expressions (21) and (22) bring the paper's analysis closer in line with actual policy behavior, rather than the backward looking thresholds considered above.

We choose parameters in line with estimates from the literature in order to gauge the quantitative impact of preemptive action on inflation and output. Parameter values for the Phillips curve are consistent with estimates in Gali, Gertler, and Lopez-Salido (2005), where $\omega_\pi = 0.65$ and $\lambda = 0.03$. For the consumption Euler equation we use $\sigma^{-1} = 0.16$ (Woodford 2003, 341), and $\omega_x = 0.52$ (Dennis 2005) indicates a substantial degree of habit persistence. In this exercise, normal policy sets $\alpha_0 = 1.5$, and the preemptive policy sets $\alpha_1 = 5$.

To generate hump-shaped responses, we focus on the demand shock (g_t), which produces a peak response in inflation one period after the shock. This calibration, together with i.i.d. shocks does not produce hump-shaped responses to cost shocks (u_t). In this case, disturbances to the Phillips curve can never trigger a preemptive switch in regime because they do not produce inflation paths that satisfy the criterion $E_t\pi_{t+1} > \pi_t$.[11]

Because the switch to more active preemptive policy at time t is triggered by the state at t and its implications for inflation at $t + 1$, the regime at $t + 1$ is not known with certainty, as it was in the previous threshold examples. In fact, with i.i.d. shocks and the present calibration, which generates a response that peaks the period after the shock, agents expect the more active policy to be in place only at time t.

Using the baseline parameter values, figure 6.10 shows impulse responses to a demand shock realized in period $t = 5$ under the endogenously switching preemptive policy (solid line), and compares them to the fixed regime policy (dashed line).[12] The fixed regime policy uses $\alpha_0 = 1.5$. The demand shock generates a delayed rise in inflation, where the peak occurs the period following the shock under both policies. Under both policies, the shock raises inflation and creates an expectation of higher future inflation. This triggers a preemptive rise in rates that partially offsets the subsequent rise in inflation and reduces output.

What does implementing a preemptive, threshold switching policy buy the monetary authority? This question is answered by isolating the expectations formation effects that arise under the preemptive policy, but are absent from the fixed regime. Figure 6.11 mimics the shock intervention exercises in Leeper and Zha (2003) to create a sequence of i.i.d. policy shocks ($\hat{\varepsilon}_t$) that allow the fixed regime policy ($i_t = \alpha_0\pi_t + \varepsilon_t$) to exactly reproduce the interest rate path that the preemptive switching policy implements (bottom panel). In the first two panels we see that under preemptive, threshold switching policy (solid lines), monetary pol-

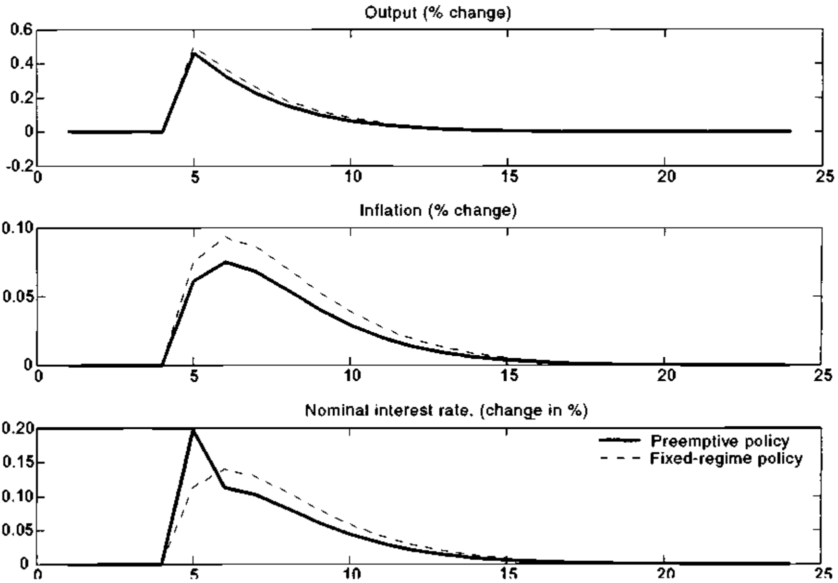

Figure 6.10
Preemptive policy strike against inflation in the hybrid new Keynesian model
Note: Fixed regime sets $a = 1.5$; preemptive switching policy sets $a_0 = 1.5$ and $a_1 = 5$.

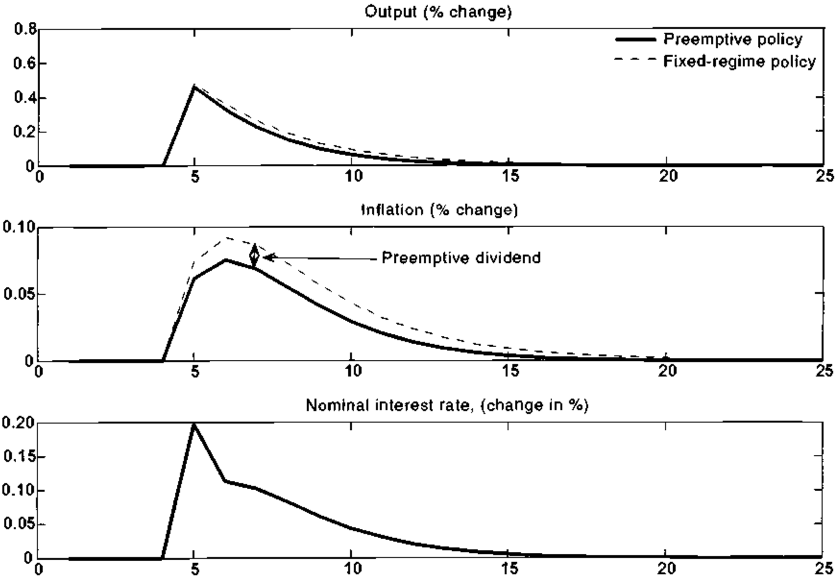

Figure 6.11
Modeling preemptive policy in fixed- and in threshold-switching regimes.
Note: Figure feeds i.i.d. policy shocks into the fixed regime policy rule to reproduce the interest rate path in the switching model. Fixed regime sets $a = 1.5$; preemptive switching policy sets $a_0 = 1.5$ and $a_1 = 5$.

icy is more effective than fixed regime policy (dashed lines) and inflation rises by much less. The figure makes apparent that in the case of a demand shock, output is stabilized also.

The magnitude of the total preemptive dividend for inflation—defined as the difference in the areas under the two inflation responses in figure 6.11—varies with agents' expectations of policy regime in periods after the initial disturbance. Expectations of future regimes, in turn, vary with the size of the initial demand shock: the larger the shock at t, the higher the probability that the preemptive state will be realized at $t + k$, and the larger are the expectations formation effects. This is shown in figure 6.12, which reports the long-run effect on the price level of a demand shock at t of a size given by the x-axis under preemptive policy (solid line), and fixed regime less active policy (dashed line). As in figure 6.11, i.i.d. policy shocks are added to the fixed regime policy to match the interest rate path under switching. The long-run preemption dividend for inflation increases monotonically with the size of the

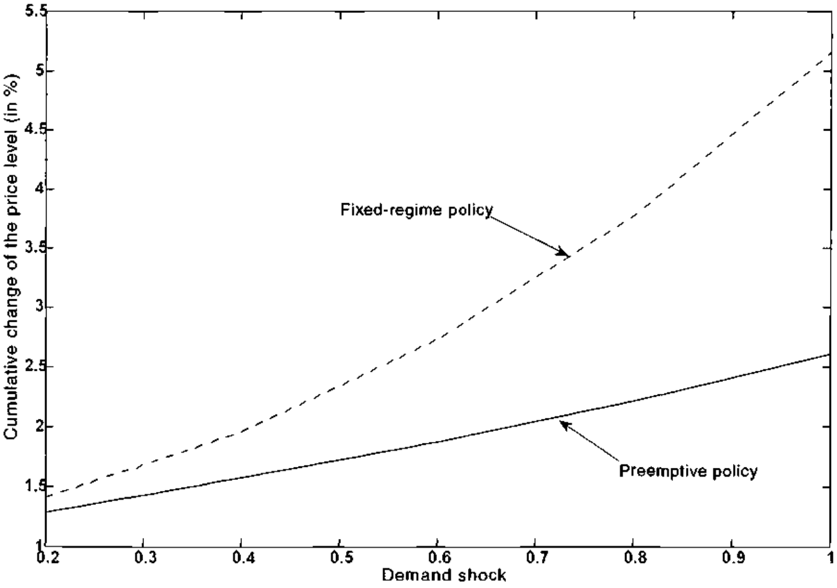

Figure 6.12
Preemption dividend as a function of size of demand shock.

Note: Plots the total long-run effect on the price level for any given sized demand shock for preemptive threshold switching policy (solid line) and fixed regime with $\alpha = 1.5$; preemptive switching policy sets $\alpha_0 = 1.5$ and $\alpha_1 = 5$. Fixed regime adds i.i.d. shocks to policy rule to match interest rate path, as in figure 6.11.

shock, and can be quantitatively significant when demand shocks are large.

6.7 Concluding Remarks

Endogenous switching of the monetary authority's policy rule carries important implications for how private agents form expectations. This paper has employed threshold switching as a simple method for endogenizing policy regime changes, which has the appeal of resembling actual policy behavior in stylized form. Under threshold switching, where policy rules change when endogenous variables cross specified thresholds, symmetric shocks have asymmetric effects and the policy process generates quantitatively significant expectation formation effects. A preemptive policy rule highlights the implications expectations formation effects have on equilibrium outcomes. A monetary authority that stands ready to aggressively raise interest rates in response to forecasts of rising inflation can shift expectations, enhancing the effectiveness of efforts to stabilize inflation and output following demand shocks when compared to a fixed regime policy. The reduced volatility of inflation following a demand shock is referred to as the preemptive dividend.

This line of work raises issues for further study. First, to what should the benefits of preemptive policy be compared? This chapter contrasts the effects under preemption to those under a simple, time-invariant Taylor rule. In keeping with the second-best policy perspective, it is interesting to contrast welfare under preemption with threshold switching to "optimal implementable" policy rules, as in Schmitt-Grohe and Uribe (2007).[13] Implementable rules are constrained to make policy instruments respond to observable variables, rather than to exogenous disturbances.

A second issue emerges from the observation that (in this chapter), preemptive threshold switching appears to offer a free lunch. It reduces the volatility of output and inflation following demand shocks, but is not triggered by supply shocks for which the preemptive policy would not uniformly reduce volatility. The difference arises because supply shocks, in the calibration we used, do not generate hump-shaped responses that would induce policy regime to change. Ultimately, the existence of humped responses is an empirical question. The present work suggests that the answer to the question could have some practical implications for the behavior of monetary policy.

Endogenous regime change represents a new mechanism by which expectations formation matters in determining the impacts of monetary policy. Given the magnitudes of expectations formation effects that emerge from conventionally calibrated new Keynesian models with threshold switching, conducting monetary policy to manage expectations is potentially quite powerful.

Acknowledgments

We thank Rich Clarida, Jeff Frankel, Jesper Lindé, Lucrezia Reichlin, Ken West, and conference participants for helpful suggestions. Leeper acknowledges support from NSF Grant SES-0452599.

Notes

[1] There is also work that assumes that policy behavior switches exogenously among different exogenous rules for the evolution of policy variables (Andolfatto and Gomme 2003; Leeper and Zha 2003; Davig 2004; and Owyang and Ramey 2004).

[2] Some work examines one-time, permanent endogenous regime changes (Sims 1997; Daniel 2003; and Mackowiak 2006).

[3] This distinction follows the taxonomy in Leeper and Zha (2003).

[4] See Orphanides and Williams (2005) for a model of preemptive policy in a learning environment.

[5] The phrase "respond systematically more aggressively" may seem redundant. We use it to emphasize that the central bank is not raising the nominal interest rate because of the realization of an additive shock. Instead, it is changing the function that maps economic conditions into policy choices.

[6] To focus on endogenous policy actions, in most of the paper we dispense with the policy shock.

[7] The rule in equation (4) is written in terms of percentage deviations from steady-state. Underlying equation (4) is a rule in levels of variables with a state-dependent intercept that varies to keep the deterministic steady-state constant across regimes.

[8] The variance of the shock (σ_v^2) is also important. For simplicity, this dimension is not analyzed.

[9] The graph is drawn for $\rho = 0.01$; when $\rho = 0$ the model collapses to the trivial solution $\pi_t \equiv 0$.

[10] Although the figure is drawn for particular values of lagged inflation—$\pi_{t-1} = \pm 0.37434$—the magnitude of π_{t-1} is unimportant for the relative position of the solid line. Expectation formation effects are generated by the likelihood of a change in future regime, which depends on the sign of π_{t-1}, not its magnitude.

[11] There is some empirical evidence supporting this. Based on VAR evidence, there is a broad consensus that demand shocks tend to produce humps in output and inflation (Gali 1992; Leeper, Sims, and Zha 1996). The evidence on whether supply (or cost) shocks also

produce humps, particularly in inflation, is more mixed. Gali (1992) finds they do not, while Ireland (2004) finds that they do.

12. The nonlinear endogenous switching model has a stochastic steady-state—defined as the state the economy converges to when all shocks are set to zero—that differs from the linear model (where the steady-state is zero inflation and zero output gap). For comparison, the impulse responses are reported with the non-zero steady-state swept out of the nonlinear model. Because the stochastic steady-states for inflation and output are below zero, the figures understate the actual difference between policies.

13. In linear frameworks, the fully optimal monetary policy is linear in the exogenous shocks. Clearly, endogenous switching policy cannot improve on optimal policies.

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Appendix

Numerical Solution Method

Threshold switching induces nonlinearity into each model that requires the use of numerical methods to obtain a solution. We use the monotone map algorithm, as in Coleman (1991), which is an iterative method that constructs decision rules over a discretization of the state space. To initialize the algorithm, we use the solutions from each model's fixed regime counterpart, but also check that the final solution is not sensitive to initial conditions by pertubating these initial conditions. The final solution is invariant with respect to perturbations in the initial rules, suggesting the solution is locally unique.

As an example, consider the new Keynesian model with threshold switching and supply shocks. Implementation of the algorithm begins by taking the initial rules for inflation and the output gap, $\hat{h}^{\pi}(u_t, \pi_{t-1}) = \pi_t$ and $h^x(u_t, \pi_{t-1}) = x_t$, and substituting them into the functions describing private sector behavior and policy, yielding:

$$x_t = E_t[\hat{h}^x(u_{t+1}, \pi_t)] - \sigma^{-1}\{i_t - E_t[\hat{h}^{\pi}(u_{t+1}, \pi_t)]\}, \tag{A1}$$

$$\pi_t = \beta E_t[\hat{h}^{\pi}(u_{t+1}, \pi_t)] + \kappa x_t + u_t, \tag{A2}$$

where u_t is a zero mean, IDD random variable with a doubly truncated normal distribution and variance of σ_u^2. Monetary policy is set according to:

$$i_t = \alpha_{S_t}\pi_t, \tag{A3}$$

where:

$$\alpha_{S_t} = [1 - I(\pi_{t-1} \geq 0)]\alpha_0 + I[\pi_{t-1} \geq 0]\alpha_1. \tag{A4}$$

For a given u_t and π_{t-1}, equation (A4) determines α_{S_t}, and then substituting equation (A3) into equation (A1) yields:

$$x_t = \int_a^b \phi(u;\sigma_u^2)\hat{h}^x(u, \pi_t)du - \sigma^{-1}[\alpha_{S_t}\pi_t - \int_a^b \phi(u)\hat{h}^x(u, \pi_t)du], \tag{A5}$$

$$\pi_t = \beta \int_a^b \phi\,(u;\sigma_u^2)\hat{h}^x(u, \pi_t)du + \kappa x_t + u_t, \tag{A6}$$

where $\phi(\cdot)$ is the normal density, $a = -3\sigma^2$, and $b = 3\sigma^2$. Expectations are evaluated using trapezoid integration, so:

$$\int_a^b \phi(u;\sigma_u^2)\hat{h}^{\pi}(u, \pi_t)du = \frac{h}{2}[f_0^{\pi} + 2f_1^{\pi} + \ldots 2f_{N-1}^{\pi} + f_N^{\pi}], \tag{A7}$$

$$\int_a^b \phi(u;\sigma_u^2)\hat{h}^x(u, \pi_t)du = \frac{h}{2}[f_0^x + 2f_1^x + \ldots 2f_{N-1}^x + f_N^x], \tag{A8}$$

where $f_i^{\pi} = \phi(u_i;\sigma_u^2)\hat{h}^{\pi}(u_i,\pi_t)$, $f_i^x = \phi(u_i;\sigma_u^2)\hat{h}^x(u_i, \pi_t)$, $h = (b-a)/N$, $u_i = a + hi$, and N is the number of nodes. Linear interpolation is used to evaluate $\hat{h}^{\pi}(u_i, \pi_t)$ and $\hat{h}^{\pi}(u_i, \pi_t)$ for $i = 1, \ldots, N$ inside the integral. The relevance of threshold switching appears when evaluating the integral, since agents place positive probability on the set of shocks next period that would trigger a different monetary policy in the future.

Again, the system is:

$$x_t = \frac{h}{2}(f_0^x + 2f_1^x + \ldots 2f_{N-1}^x + f_N^x)$$

$$- \sigma^{-1}\left[\alpha_{S_t}\pi_t - \frac{h}{2}(f_0^\pi + 2f_1^\pi + \ldots 2f_{N-1}^\pi + f_N^\pi)\right],$$

$$\pi_t = \beta\frac{h}{2}(f_0^\pi + 2f_1^\pi + \ldots 2f_{N-1}^\pi + f_N^\pi) + \kappa x_t + u_t,$$

which is two equations with two unknowns, x_t and π_t. The state vector and the decision rules are taken as given when solving the system. The system is then solved for every set of state variables over a discrete partition of the state space. This procedure is repeated until the iteration improves the current decision rules at any given state vector by less than some convergence criterion, ε, set to 1e–8.

Comment

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Motivation

As a practical matter, it makes sense to think about a threshold model as being potentially relevant to describing actual monetary policy. While the mechanism featured here is not entirely novel (it bears some resemblance to properties of the equilibrium in a target zone model), the magnitude of the regime switching effect on current outcomes is large in the calibrated model. Moreover, the inflation scare example near the end of the chapter, in which policy becomes more aggressive when actual and expected inflation are rising, produces the striking result that (in response to a demand shock) inflation and the output gap are lower period by period under the threshold rule than they would be under the simple Taylor rule.

Basic Idea

In this economy, the central bank follows a version of a Taylor rule, but it also gets more aggressive if inflation gets too high. It features a threshold reaction function:

$$i = \alpha_s \pi$$

where $\alpha_s = [1 - I(\pi - 1 > \pi^*)]\alpha_0 + I(\pi - 1 > \pi^*)\alpha_1$. The authors then put this into a (graduate) textbook model. Note that the equilibrium real rate is missing from this Taylor rule. This is important because in a model with demand shocks, there will be variations in the equilibrium real interest rate that, were they to show up in the reaction function, could fully offset the demand shock effect on inflation or output. This is a model that would feature exogenous persistence with a linear Taylor rule.

Key Results and Intuition

Suppose the reaction function is linear and $\alpha = 1.5$, then Phillips curve shocks have measurable impact on inflation. Suppose now that policy is linear and $\alpha = 3$, then Phillips curve shocks have a much smaller effect on inflation as would be expected. Now suppose as in Figure 6.7 of the chapter, $\alpha_0 = 1.5$ when $\pi_{-1} < 0$, and switches to $\alpha_1 = 3$ when $\pi_{-1} > 0$. Now, when $\pi_{-1} < 0$, even though $\alpha_0 = 1.5$ in this region, the response to a positive cost shock is very close to what it would be in a linear model for $\alpha = 3$. Thus, the promise to be tough when inflation is high attenuates the response of inflation to a cost push shock when initial inflation is low. But this also goes the other way. When $\pi_{-1} > 0$, even though $\alpha_0 = 3$ in this region, the response to a negative (favorable) cost shock is very close to what it would be in a linear model for $\alpha = 1.5$.

If you stop and think about it for a moment, you realize this sort of effect is present in other models. For example, in a target zone model in which monetary policy rule changes when the exchange rate e is equal to eT (the band of the target zone), the effect of shocks on e is attenuated when $e < eT$ and money is following an accommodative rule. That this effect is as large as it is here is surprising. The calibration says that a central bank operating with a Taylor rule of 1.5 will have virtually the same effectiveness against a positive inflation shock as a central bank operating with three, so long as it switches to three if inflation gets too high. But is also goes the other way. It says that a central bank operating with a Taylor rule of three will have the virtually the same ineffectiveness in response to a negative inflation shock as a central bank operating with 1.5, so long as it will switch back to 1.5 if inflation gets too low.

A Richer Model

The inflation scare model featured in the next section of the chapter is very well done. It features inflation inertia and habit persistence, and adds a policy regime switch when $\pi > \pi_{-1}$ and $E\pi_{+1} > \pi$. With an inflation scare reaction function, the central bank gets more aggressive when inflation has been and is expected to be increasing.

The authors show that, in response to a demand shock with an inflation scare reaction function, the output gap is smaller in each period and inflation is lower in each period. This is accomplished with a preemptive rate hike. Now this appears to be a free lunch, but the example would be more convincing for a cost push shock. The reason is that a simple Taylor rule can get to first best in the case of a demand shock (the omission of the equilibrium real rate from the policy rule really matters here).

Final Thoughts and Questions

We know even in linear models that forward looking Taylor rules can generate multiplicities if α is too large. My intuition is that multiplicities could be prevalent for reasonable parameters, especially for the inflation scare model. Also, since the macro model to which the threshold rule is appended is standard and well studied, we know that these threshold rules are neither optimal under discretion nor time consistent under commitment.

Comment

Jesper Lindé, Sveriges Riksbank and CEPR

Introduction

This excellent chapter studies the effects of endogenous threshold monetary policy rules (regimes). In this way, it extends previous work in the literature, which has typically assumed that regimes change exogenously.[1] There are also a few papers that examine the consequences of a one-time permanent endogenous regime change; the chapter extends this literature by allowing for the possibility of an arbitrary number of future regime shifts. On the surface, the analysis and the results in the chapter are so straightforward and well written that they almost appear trivial. But, in fact, that is not the case, and anyone that has worked on solving nonlinear models should appreciate the computational level of sophistication, and how easily the results are communicated in the chapter. The authors show that their simple threshold setup gives rise to an equilibrium characterized by the following three features.

First, endogenous policy rule switching results in cross-regime spillover effects, i.e. the knowledge that the coefficients in the policy rule may switch at some given future state affects agents decisions today. A useful example is that a policy rule, which responds less than one-to-one to inflation if inflation is below (above) a certain threshold, may still give rise to a determinate equilibrium if the central bank can commit and announce that it will respond more than one-to-one if inflation exceeds (falls below) the threshold value. Consequently, even if a central bank does not fulfill the Taylor principle for every state of the economy, the policy setup may still result in a unique well-defined equilibrium because of the expectation formations effects induced by the fact that the central bank will act according to the Taylor principle, if inflation (or output) passes certain thresholds.[2] Thus, if a shock increases the likelihood of hitting the threshold in the policy rule, e.g. a switch from a passive to a more activistic rule, this will affect agents' decisions via expectations, although the active regime may never materialize.

Second, the authors' setup also implies that typical macroeconomic shocks (like policy shocks) have nonlinear effects on the economy. They cite an empirical literature which supports this property, or their model, to build credibility for their modelling framework. But an important distinction is how the nonlinear effects of various shocks are generated. The typical explanation is that they are due to nonlinearities in the structure of the economy. In the present setup, all nonlinearities stem from the threshold policy rule.[3]

Third and last, the model is able to account for a preemptive policy dividend. They define the preemptive policy dividend as the difference in the inflation forecast, conditional on the same interest path for a fixed policy rule regime and the threshold switching model in a situation where inflation expectations are rising between period t and $t + 1$. The given interest rate path in the fixed regime case is generated by injecting policy shocks, and therefore has direct effects on the inflation forecasts. But standard models with a fixed regime can never generate the expectation formations effects that the endogenous threshold switching model can generate. Hence, the ability of the central bank to credibly announce that it will change the policy response if inflations expectations rise above a certain threshold, implies that the central bank does not have to increase the interest rate as much as the fixed policy rule banker to stabilize inflation in practice. The notion of a preemptive policy dividend plays a central role in central bank thinking according to the authors, and they cite work by Goodfriend (2005) which argues that the increase in the Federal interest rate during 1994 was an example of a successful preemptive strike, as inflation remained low and long-term interest rates declined.

This chapter was enjoyable to read, and offers analysis of the basic properties of threshold switching rules in a standard new Keynesian model. There is little reason to disagree with their analysis. What is still considered to be an open question is to what extent threshold switching models represent a promising avenue to model monetary policy behavior in macro models. The first issue discussed is whether threshold switching rules, as modelled in this chapter, are an improvement to standard exogenous regime switching models. Second, the model has certain empirical implications, which will be compared with the data. So far, (basically) every paper in the monetary policy literature has adopted a fixed policy rule regime perspective (Christiano, Eichenbaum, and

Evans 2005; and Smets and Wouters 2003), and it is therefore of interest to study the basic properties of the data in order to get a feeling for whether the implications of the switching environment in the chapter have strong empirical support or not.[4] Ultimately, for the ideas contained in this paper to be really influential, the authors will have to provide empirical support for modeling endogenous regime switching rules having an empirical advantage, as compared to what is currently standard practice.

Endogenous Threshold versus Exogenous Regime Switching Rules

Throughout the chapter, it is assumed that the central bank can fully commit to a policy rule of the following type:

$$i_t = \kappa(S_t) + \alpha(S_t)\pi_t + \gamma(S_t)x_t + \varepsilon_t, \tag{1}$$

where the notation $\kappa(S_t)$, $\alpha(S_t)$, and $\gamma(S_t)$ reflects that the coefficients are functions of the state of the economy. For instance, the authors typically assume that $S_t = \{\pi_t, \pi_{t-1}, \pi^*, x_t\}$, where π_t is the inflation rate in period t, π^* the inflation target, and x_t some measure of the output gap. A simple example of equation (1) is as follows: suppose that $\kappa(S_t) = \gamma(S_t) = 0$ for all S_t, and that:

$$\alpha(\pi_{t-1} - \pi^*) = [1 - I(\pi_{t-1} - \pi^*)]\alpha_0 + [I(\pi_{t-1} - \pi^*)]\alpha_1, \tag{2}$$

where I is an indicator function such that $I(\pi_{t-1} - \pi^*) = 0$ if $\pi_{t-1} - \pi^* < 0$ and unity otherwise, and that $\alpha_0 < \alpha_1$. The authors typically assume that $\alpha_0 = 1.5$ and $\alpha_1 = 5$ in their experiments. Until this work, the literature with time-varying policy rule coefficients has worked with rules where the switching between coefficients α_0 and α_1 constitute exogenous events. As noted by the authors in their introduction, the notion of exogenous switching is inconsistent with how we model monetary policy as purposeful in modern macro models, because purposeful monetary policy does not switch coefficients in Taylor-type rules at exogenous events. But this viewpoint is stemming from a normative perspective. From a more empirical perspective, it is not clear that commitment to fixed endogenous thresholds is an improvement to exogenous Markov processes for policy rule coefficients. It is not certain that central banks would like to make such a commitment, and even if they did, it is not clear that they would be believed to be credible among households. However, both parties may be willing to accept the notion of time-varying thresholds. A simple way of modeling this in equation (1) would be to assume that the thresholds follow exogenous Markov processes. In terms of the example equation (2), it would have to be assumed that the inflation target was time-varying, which I find to be a very plausible assumption from a more positive perspective.

Now return to more normative considerations in association with discussing the preemptive policy premium. By adding a version of equation (1) to a standard new Keynesian type of model (Phillips curve for π_t, IS curve for x_t), the authors demonstrate that the model can generate a preemptive policy (PP) premium for aggregate demand shocks. For supply shocks, the chapters setup does not give rise to a PP premium. Setting aside the model-specific issue of whether it was actually demand shocks in 1994 that were giving rise to the increase in expected inflation and long-term interest rates, a more challenging problem for the literature on threshold switching rules is to set out an environment where it is useful for the monetary policy authority to create PP premium. In the linearized new Keynesian model economy, there is no preemptive policy dividend (linear model, linear policy optimal). Therefore, it would be more convincing to do the experiment in an environment which would rationalize the nonlinear policy response, i.e. change the modelling setup. Using a nonlinear structural model, or time-varying deep parameters or shock processes, offers one such opportunity. Alternatively, the authors can motivate their setup by checking whether the threshold switching rule performs better than the best-practice operational Taylor rules in their model economy. To motivate the latter experiment, it must be assumed that the central bank is not able to observe the shocks in period t; it is only allowed to respond to variables known in period $t - 1$.[5]

Empirical Considerations

For reasons already discussed, it is believed that analyzing the empirical support for the endogenous threshold switching framework suggested in the chapter is of key importance. In this section, the results of some simple exercises will be provided in order to shed some preliminary light on this issue.

First of all, one may ask if there exists independent evidence that central banks have asymmetric preferences over inflation and output. This would provide a rationale for endogenous threshold switching policy rules. The authors cite the work of Surico (2003, 2007), who finds this to be the case for the European area and the United States. A weakness of this evidence is that neither the European area nor the United States have been explicit inflation or output targeters during the sample period under consideration, so it would be of interest to complement this evidence by also analyzing other countries. An alternative approach would be to contrast the fit of the type of threshold policy rules presented in the chapter, with fixed regime rules. This is presumably difficult, because allowing for interest smoothing provides a good fit in fixed regime rules, both in the pre-1982 period and the post-1982 period (Sims and Zha 2006).[6]

So what could then be done? One implication of the endogenous threshold environment is that inflation distributions should be nonnormal (see section 6.5.3 and figure 6.4 in the chapter). More specifically, the inflation distributions should most plausibly be skewed to the left (i.e. the mean should be lower than the median), because the central bank is more willing to accept periods with lower inflation rates than periods with higher inflation rates. In figure 6C.1, annualized inflation rates are plotted in percentage units—that is 400 ln($PGDP_t/PGDP_{t-1}$)—for the European area, Sweden, and the United States. All three time series appear to display a similar low frequency component, but there are considerably more high frequency movements in the Swedish series, in particular during the preinflation targeting period. Figure 6C.2 displays his-

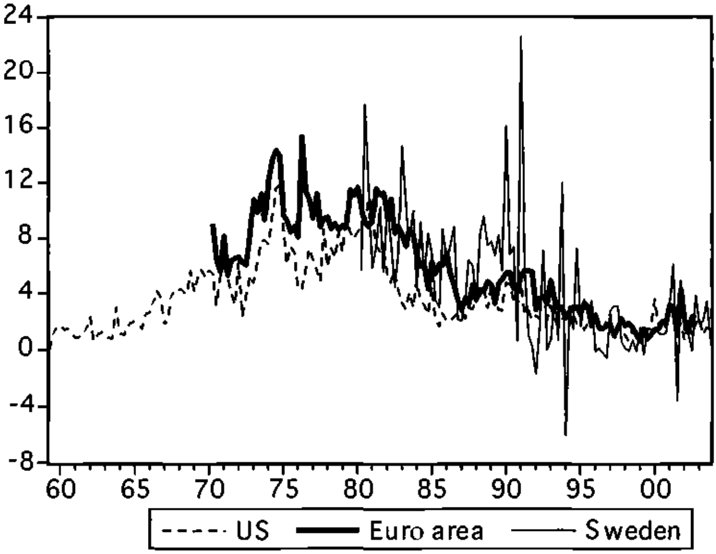
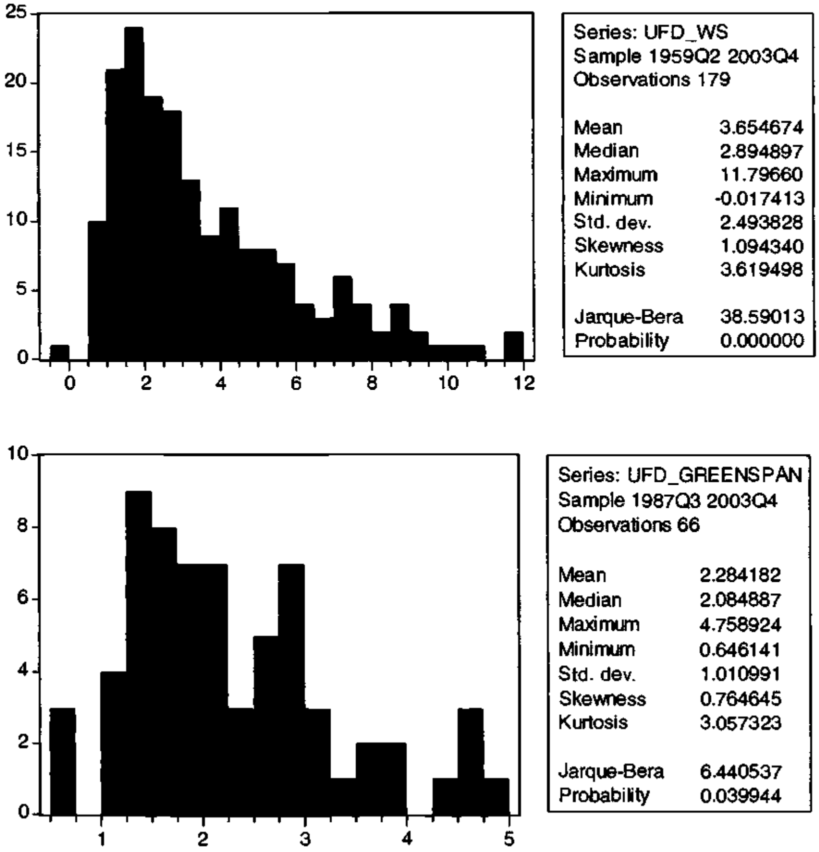


Figure 6C.1
Annualized GDP Inflation Rates in Selected Countries



Series: UFD_WS
Sample 1959Q2 2003Q4
Observations 179

Mean	3.654674
Median	2.894897
Maximum	11.79660
Minimum	-0.017413
Std. dev.	2.493828
Skewness	1.094340
Kurtosis	3.619498
Jarque-Bera	38.59013
Probability	0.000000

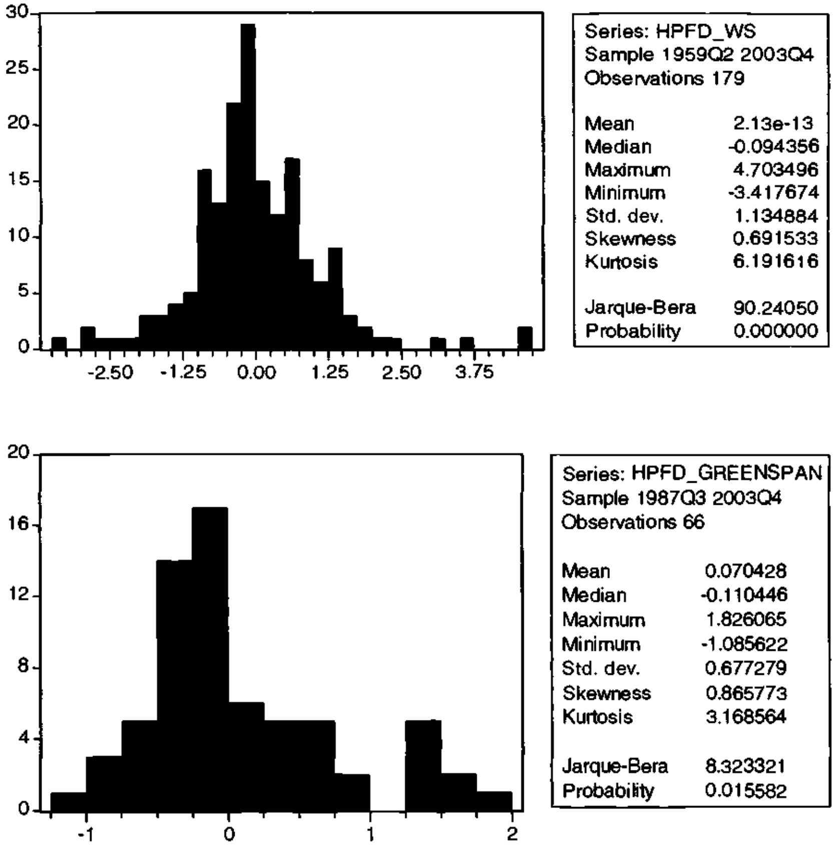
Series: UFD_GREENSPAN
Sample 1987Q3 2003Q4
Observations 66

Mean	2.284182
Median	2.084887
Maximum	4.758924
Minimum	0.646141
Std. dev.	1.010991
Skewness	0.764645
Kurtosis	3.057323
Jarque-Bera	6.440537
Probability	0.039944

Figure 6C.2
Inflation Distributions in the U.S.

Note: unfiltered data (UFD_WS) whole sample, Deviation from HP trend (HPFD_WS), Unfiltered data Greenspan period (UFD_GREENSPAN), Deviation from HP trend Greenspan period (HPFD_GREENSPAN).

tograms for the U.S. inflation rates, and reports the Jarque-Bera test statistic for the null of the distribution being normal. The two diagrams to the left show results for unfiltered inflation rates for two different sample periods (the whole sample and the Greenspan period), while the two diagrams to the right show results for Hodrick-Prescott (HP) filtered inflation rates (i.e. a time-varying inflation target has been removed). None of the distributions are normal, thereby supporting the implications of the authors' model. However, as is evident from the unfiltered data in particular, it is not the case that the distributions are



Series: HPFD_WS
Sample 1959Q2 2003Q4
Observations 179

Mean	2.13e-13
Median	-0.094356
Maximum	4.703496
Minimum	-3.417674
Std. dev.	1.134884
Skewness	0.691533
Kurtosis	6.191616
Jarque-Bera	90.24050
Probability	0.000000

Series: HPFD_GREENSPAN
Sample 1987Q3 2003Q4
Observations 66

Mean	0.070428
Median	-0.110446
Maximum	1.826065
Minimum	-1.085622
Std. dev.	0.677279
Skewness	0.865773
Kurtosis	3.168564
Jarque-Bera	8.323321
Probability	0.015582

Figure 6C.2
Continued

skewed to the left, they are rather skewed to the right. The two diagrams with HP filtered data are less skewed, but have rather fat tails which leads to the rejection of the normality hypothesis.[7] By and large, Figure 6C.2 lends little support to the authors' model, unless one is willing to assume that inflation dynamics is (to a relatively large extent) driven by unforecastable shocks.

Another implication of the chapter's setup is that the one-step ahead forecast errors for the interest rate in standard linear VARs should be autocorrelated. This is the case due to the fact that if the policy response coefficients have changed over time (assuming that different regimes have in fact materialized), the coefficients that are estimated in a linear VAR will be a weighted average of the various rules that have been in place.

As a consequence, the one-step ahead forecast errors will be autocorrelated. In particular, this should be the case during the preemptive strike in 1994, which the authors argue to be an example where the policy rule response changed. This implication is true regardless of how monetary policy is identified. Moreover, but probably to a lesser extent, it is the case that the one-step ahead forecast errors for the other variables in the system should also be autocorrelated. Furthermore, the linear VAR should underpredict the interest rate path during 1994, and overpredict the future inflation rates during this episode according to the chapter framework.

To shed some light on whether these empirical implications are borne out by the data, two VARs have been estimated and used to compute one-step ahead forecast errors and generate genuine pseudo out of sample forecasts. The first VAR is the semi structural (ten variables) VAR estimated by Altig et al. (2004), and the second is just a simple unrestricted (UR) trivariate VAR (quarterly growth rate in GDP per capita, inflation, and the Federal Funds rate).[8]

In figure 6C.3 the annualized residuals for output, inflation, and the Federal funds rate are reported. As can be seen from the figure, and in line with the implications of the chapter setup, the residuals for the Federal funds rate display the highest degree of autocorrelation. For the whole sample period, however, the autocorrelation coefficient is close to zero for both VARs, because of the large spikes during the 1970s and the beginning of the 1980s. For the post-1982 period, the autocorrelation coefficients are about 0.34 and 0.20 according to the ACEL and UR VARs, respectively. For the Greenspan period, they are both about 0.49, and significant in the two VARs. So the Greenspan period offers support for the chapter setup, but the post-1982 period does not to the same extent.

In figures 6C.4 and 6C.5, I report the pseudo out-of-sample forecasts for the Greenspan period for three horizons along with the actual outcome.[9] Figure 6C.4 reports results for the ACEL model, and Figure 5 for the unrestricted VAR. In both figures, output per capita and inflation have been transformed to yearly growth rates. Both figures display an increase in forecasted inflation during 1994, in particular at longer horizons. Both models also underpredicted the rise in the Federal funds rate (except the ACEL VAR at the two year horizon). So in this sense, both models support the idea of a preemptive strike during 1994. However, it is also clear from both figures that the forecast errors were not exceptionally large for the interest rate during this episode, which appears to be an implication of the chapter framework.

To conclude, neither the simple unconditional (inflation distributions)

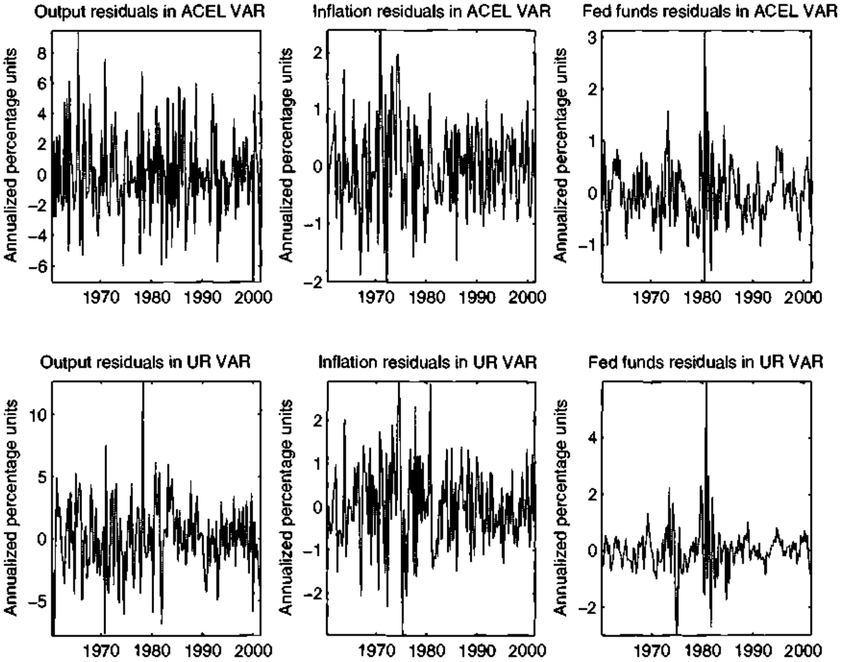


Figure 6C.3
Reduced Form Residuals for Selected Variables in the Altig et al. (ACEL) structural ten-Variables VAR and an unrestricted (UR) trivariate VAR.

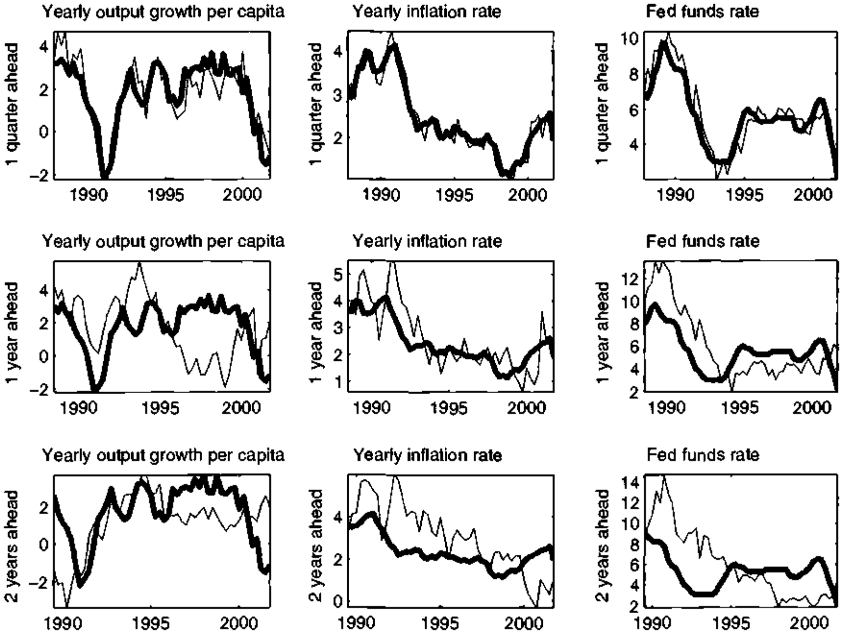


Figure 6C.4
Actuals (thick) versus ACEL Structural 10-Variables VAR Forecasts (thin).

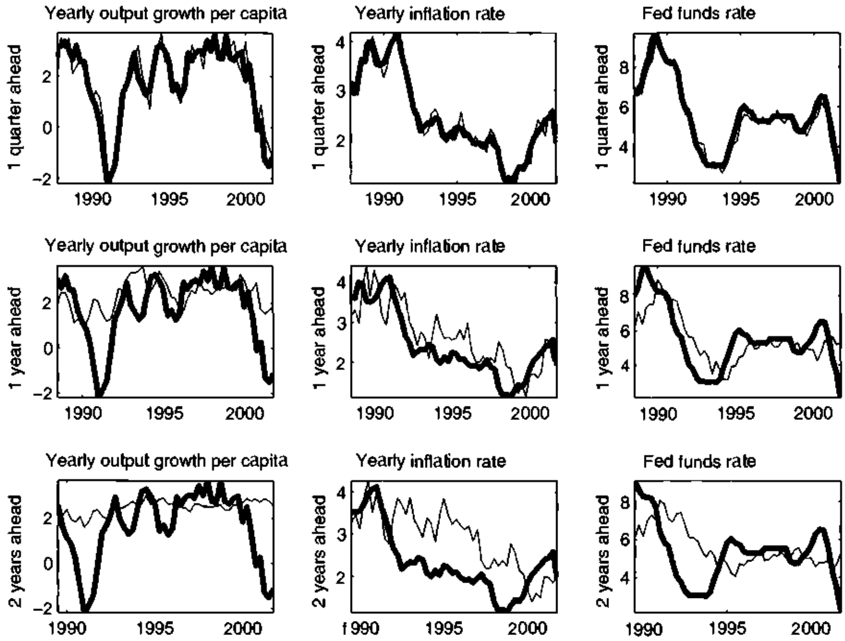


Figure 6C.5
Actuals (thick) versus Unrestricted 3-Variables VAR Forecasts (thin).

nor the conditional (VAR results) empirical exercises considered can be said to provide strong support for or against the threshold switching setup suggested in the chapter. Therefore, it will be interesting to follow the results of more refined empirical work in this area.

Notes

[1] See the literature cited in note 1 in the chapter.

[2] Davig and Leeper (2006b) argue that this implies that the empirical findings by Clarida, Galí, and Gertler (2000) (i.e. that the United States did not fulfill the Taylor principle during the 1970s) cannot (without further analysis) be taken to imply that the Federal conduct of monetary policy was an integral part of the great inflation.

[3] See Jacobson, Lindé, and Roszbach (2004) for an analysis where the effects of monetary policy shocks are strongly state dependent, although the coefficients in the policy rule are constant.

[4] From a more practical viewpoint, the latter perspective is also important, given that few (if any) central banks incorporate any sort of regime switching monetary policy behavior in the new generation of monetary models.

[5] This latter possibility is also noted in the chapter conclusions.

6. From a theoretical perspective, there is a good reason to include lagged interest rates in the policy rule, as interest smoothing is typically welfare beneficial in new Keynesian models considered by the authors (Woodford 1999).

7. As might be conjectured from Figure 1, the results are very similar for Sweden and the European area, and (therefore) no histograms are reported for those series.

8. Both VARs use data for the period 1959Q2–2003Q4. The Altig et al. (2004) VAR is semi-structural because only three out of ten possible shocks are identified, and four lags are used for both VARs.

9. With the terminology pseudo out of sample, it is meant that the one-quarter ($t + 1$), one year ($t + 4$), and two year ($t + 8$) ahead forecasts are computed using VAR estimates that are based on data up to period t. The first forecasting period is set to be 1987Q3.

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