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Regime Changes and Monetary Stagflation

Edward S. Knotek II

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Abstract: This paper examines whether monetary shocks can consistently generate stagflation in a dynamic, stochastic setting. I assume that the monetary authority can induce transitory shocks and longer-lasting *monetary regime changes* in its operating instrument. Firms cannot distinguish between these shocks and must learn about them using a signal extraction problem. The possibility of changes in the monetary regime greatly improves the ability of money to generate stagflation. This is true whether the regime actually changes or not. If the monetary regime changes on average once every ten years, stagflation occurs in 76% of model simulations. The intuition for this result is simple: increased output volatility due to learning coupled with inflation inertia produce conditions conducive to the emergence of stagflation. The incidence of stagflation can be reduced by a stable, transparent central bank.

Keywords: Stagflation, monetary regime changes, signal extraction, sticky information

JEL classifications: E52, E31

I   Introduction

Stagflation has not occurred in the U.S. in more than twenty years. This does not mean, however, that it has disappeared from the minds of policymakers or the popular press. Spikes in oil prices continually renew interest in the topic due to the conventional view that oil prices were a central factor in the 1970s' stagflation.

Yet multiple oil price fluctuations in the last twenty years have not been followed by stagflation, suggesting that such a connection is tenuous or dependent upon other factors. This paper questions the extent to which oil shocks—or, more broadly, any supply shocks—are necessary to generate stagflation. In short, I find that they are not necessary. I present evidence that a dynamic, stochastic model with monetary shocks can consistently generate stagflation similar to the U.S. experience of the 1970s.

The key stagflation-generating mechanism is the possibility that the monetary authority may implement two types of changes to its operating instrument which are not immediately distinguishable to price-setters in the economy. In this paper, the monetary authority can exogenously induce transitory as well as long-lasting changes in the money growth rate. The latter are *monetary regime changes*; they occur stochastically and can take on a continuum of values. While the monetary authority has perfect knowledge regarding the monetary regime, I assume that firms do not, requiring them to learn about the regime via a signal extraction problem. I show the consequences of such learning in an environment characterized by nominal rigidities which prevent firms from continuously updating their information.

Using U.S. historical data as a guide, I propose an algorithm to identify stagflation in quarterly data. The algorithm requires a particular quarter to satisfy three conditions in order to be classified as "stagflationary": (1) inflation must be at least one standard deviation above its long-run average; (2) output must be below trend and have worsened relative to trend since the previous quarter; and (3) either the preceding or succeeding quarter must also satisfy (1) and (2) as well. Applying this algorithm to the simulated model, I find that stagflation is very rare when regime changes are not possible, occurring in only 6% of simulations.

Adding the possibility of changes in the monetary regime dramatically alters these results. For instance, suppose that the monetary regime changes once every ten years on average. When this is the case, the simultaneous incidence of high inflation and below-trend

output which characterize stagflation occurs at least once in 76% of simulations. Moreover, the monetary regime need not change to produce similar results: firms' uncertainty associated with the fact that the monetary regime can change is enough to generate stagflation. The intuition for this result is simple: the learning process required when transitory shocks and regime changes are indistinguishable induces volatility in the output gap which, when combined with inflationary inertia, produces conditions conducive to the appearance of stagflation. This is true even for relatively rare regime changes—i.e., on the order of once every thirty years.

Removing price-setters' learning reduces the incidence of monetary stagflation. When the central bank's actions are transparent and price-setters can distinguish between transitory shocks and regime changes, stagflation occurs less frequently in the simulations. Most of the remaining stagflation is related to changes in the monetary regime. This suggests that stable monetary authorities (i.e., those which do not undergo regime changes) with transparent policies can reduce the likelihood of monetary stagflation. Alternatively, if the central bank were to announce regime changes prior to implementing them, it is possible the remaining stagflationary episodes would be eliminated.

This paper contributes to a literature that stresses potential connections between money and stagflation. In two recent works, Barsky and Kilian (2002) and Orphanides and Williams (2005a) present models that combine elements of regime changes and learning, and they show that stagflation can arise in response to particular sets of shocks. This paper makes regime changes a stochastic component of the economy and shows that stagflation from monetary shocks arises regularly within a dynamic setting. Restrictive assumptions on the timing of the regime change or the sequence of shocks are not required, nor is a regime change per se necessary for an economy to experience stagflation. The particular form of monetary regime changes, while similar to that employed by Andolfatto and Gomme (2003), allows for a wider range of possible outcomes.

The outline of this paper is as follows. Section II examines the U.S. economic history of the 1970s and early 1980s to construct an algorithm for finding stagflation in quarterly data. Section III develops the sticky information model used in the analysis, introduces the monetary authority, and explains how firms learn about the monetary regime. I simulate the model and interpret the results in Section IV. I also consider how the results would be altered if certain assumptions in the original setup were altered. Section V concludes.

II   Stagflation and the U.S. Experience

Most commonly, stagflation is thought of as the unfortunate coincidence of falling output and fast-rising prices. In a static AS-AD model, such a result must be due to a leftward shift of the aggregate supply curve. Combining these facts, introductory and intermediate students of macroeconomics quickly conclude that stagflation in the 1970s and early 1980s had to be caused by supply shocks, thereby typically implicating oil.

This simplification brings up several points. First, stagflation is not as well-defined, either in theory or in the data, as these students might believe. Second, the price of oil has surged several times since the 1970s without the stagflationary episodes this analysis appears to ensure.[1] Finally, many more shocks buffeted the economy in the 1970s than oil shocks; see, e.g., Blinder (1979), Bruno and Sachs (1985), Helliwell (1988), and Barsky and Kilian (2002). Each of these studies assigns to monetary policy a varying degree of responsibility in causing the stagflationary experiences of the 1970s and early 1980s, yet the former three stress the inclusion of some type of causal role emanating from the supply side of the economy. To determine whether monetary shocks in the context of a model can generate stagflation, I first examine the U.S. experience to establish exactly what "stagflation" means.

The Data for this Study

The data for this study were collected from the St. Louis Fed's Federal Reserve Economic Database (FRED). Stagflation is analyzed using data on real GDP and the GDP deflator. Real GDP is in billions of chained 1996 dollars, seasonally adjusted at annual rates. The corresponding series for the GDP deflator is the seasonally adjusted chain-type price index with base year 1996. Both series are from the BEA. I also use data from the Federal Reserve Board of Governors on seasonally adjusted M2 as the measure of the money stock. All series run from 1959:1 to 2002:4. To compare the stagflation findings using output with those using

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[1] The connection between oil and recession (e.g., Hamilton 2003) is distinct from the connection between oil and stagflation in the 1970s that dominates conventional wisdom.

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unemployment, I examine the evolution of the monthly civilian unemployment rate in the U.S. based on seasonally adjusted data from the Bureau of Labor Statistics.

<u>Stagflation in the United States</u>

One problem in identifying stagflation is that, unlike Cagan's (1956) classic definition of hyperinflation, there is not a similar consensus regarding the exact definition of stagflation. This should come as little surprise: semantically, the terms "stagnation" and "inflation" have a variety of interpretations, as would their contraction. In some ways, stagflation is the classic "I'll-know-it-when-I-see-it": most agree that the U.S. experienced stagflation in the 1970s and early 1980s, but nearly nobody defines exactly what it was that made the experience stagflationary nor provides precise beginning and ending dates. For instance, Blinder's (1979) first sentence reads, "*Stagflation* is a term coined by our abbreviation-happy society to connote the simultaneous occurrence of economic *stag*nation and comparatively high rates of in*flation*." Similarly, Bruno and Sachs (1985) in their introduction state, "The period of 'stagflation' (stagnation combined with inflation) broke out with a vengeance during 1973–75." Neither returns to give a more rigorous definition. Iain Macleod, who is recognized as the creator of the term, defined it as "not just inflation on the one side or stagnation on the other, but both of them together."[2]

The data yield important clues in defining stagflation. The historical record for the U.S. for output and GDP deflator inflation from 1970 to 1983 is displayed in Figure 1. The annual data are striking. First, real GDP growth was negative for four years during this time: 1970, 1974, 1980, and 1982. (Part or all of these years were NBER-defined recessions.) The largest contraction came in 1974, when real GDP fell by 2.2%. There were also three years—1972, 1978, and 1983—of rapid GDP growth exceeding 6%. Second, there were two inflationary peaks: in 1974 at 10.2%, and in 1980 at 9.4%. Both coincided with negative real GDP growth. Thus it seems logical that 1974 and 1980 were stagflationary years: the economy was not only stagnant but was contracting, and inflation was not only very high but had also accelerated from the previous year in each case.

Less clear are the years immediately preceding and following 1974 and 1980. Relative to the peak years of 1972 and 1978, output growth was markedly lower in 1973 and 1979, at 3.9%

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[2] As cited in Nelson and Nikolov (2004).

and 1.4%, respectively, while inflation in both years was high (above 6.5%) and accelerating. Depending on the extent to which the economy must be "stagnant"—or, in a dynamic sense, "stagnating"—these years may be construed as stagflationary as well. Meanwhile, inflation in 1975 and 1981 had fallen from its peak in the previous year but was still high at 7.2% and 8.0%, respectively. Output growth in 1975 had rebounded to 2.6% and was trending up, whereas in 1981 output growth was 1.2% before plummeting the following year.

While I rely on output and deflator inflation data for comparison with the model economies, examining the unemployment rate confirms the severity of the situation in the labor market in 1974 and 1980. As Figure 2 shows, unemployment surged from 5.1% in January, 1974, to 8.1% in January, 1975, before peaking in May. There was a similar but less severe increase in 1980, when unemployment rose from 6.3% in January to 7.7% in July before falling off slightly. The spikes in unemployment in 1974 and 1980 reinforce the idea that these were stagflationary years by nearly any definition. However, they do little to answer the question of whether the preceding and following years should also be classified as stagflationary.

To assist in identifying exact stagflationary dates, Figure 3 displays quarterly data for the period. To avoid volatility in quarterly real GDP growth, the measure of economic activity is the output gap based upon the Hodrick-Prescott (1997) filter. This measure of the output gap was negative on four occasions, ignoring the singular quarter in 1978: 1970:1–1972:1, 1974:3–1977:2, 1980:2–1980:3, and 1981:4–1983:4. (Once again, all four periods at least partially coincide with NBER-defined recessions.) Substantial peaks occurred in 1973:2 and 1978:4. Quarterly inflation, meanwhile, was high throughout most of the period. Over the longer period 1959:1–2002:4, the average quarterly inflation rate was 3.7% (at an annual rate). Compared with this long-run average, inflation was above average continuously between 1972:3 and 1982:4. If we define "high inflation" as an inflation rate more than one standard deviation above its long-run average—in this case, above 6.2%—then the U.S. experienced high inflation between 1973:2 and 1975:1, briefly again in 1975 and 1977, and between 1977:4 and 1981:4. Inflation also reached two local maxima: 12% in 1974:3 and 10.6% in 1980:4. The peak in 1974 coincides with a negative output gap for the third quarter but the second peak does not, as the output gap was positive and rising.

I mention the periods of above-average, high, and accelerating inflation because of the controversy that surrounds the definition of stagflation and the dilemma in the data; see Barsky

and Kilian (2002) and Blanchard (2002). If stagflation requires that the economy be stagnant—defined as an output gap that is negative—coupled with high inflation, then we have such an experience from mid-1974 into 1975, late 1976 into 1977, and again in 1980.[3] But if inflation must be high and accelerating from one quarter to the next while output is below the natural rate, we are left with fewer choices: 1974:3, 1975:3, 1976:4, and 1980:2. The annual data downplay the potentially stagflationary episodes in 1976 and 1977: from Figure 1, real GDP growth was 4.5% in 1976 and inflation was at a local minimum of 5.2%, while real GDP growth was even higher at 4.9% in 1977. Thus after examining both the annual and quarterly data we are left with two viable stagflation candidates: 1974–75 and 1980.

A Stagflation Algorithm

Using the above analysis as a guide, I propose an algorithm for identifying stagflation in quarterly data. This algorithm is applied to the model economy simulations in the next sections. If a particular quarter satisfies the following three criteria, I label it "stagflationary." A "stagflationary episode" is then a sequence of consecutive stagflationary quarters.

(1) Inflation must be relatively high. Inflation is "high" in a particular quarter if it is at least one standard deviation above its long-run average. For the purposes of this paper, the long-run is considered to be a 176-quarter period, matching the 1959–2002 time span.

(2) The economy must be "stagnant." This is satisfied if the output gap for the quarter is negative *and* the output gap has decreased since the previous quarter. Thus output is below trend and worsening relative to trend.

(3) A stagflationary episode must last longer than one quarter. Either the preceding quarter or the quarter that follows must also satisfy (1) and (2) in order for a given quarter to be considered stagflationary. This prevents a temporary negative blip from being counted as a stagflationary episode and is in the spirit of the negative connotation of the term.

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[3] This rules out the possibility illustrated in Blinder (1979, 2002) whereby an aggregate demand shock that causes output to overshoot the natural rate results in a stagflationary period as output returns to normal. This is consistent with Blanchard's (2002) comment that unemployment must be high—i.e., above the natural rate—during a stagflation and with the conventional wisdom that the virulence of a stagflationary experience caused by an aggregate supply shock, in the most basic introductory sense, comes from an output gap that is negative in conjunction with inflation.

Applying this algorithm to the U.S. data from 1959 through 2002 yields five quarters—1974:3, 1974:4, 1975:1, 1980:2, and 1980:3—that are classified as stagflationary. These observations match the graphical examination of the historical record and can be seen in the context of the period 1959–2002 in Figure 4.[4]

III Sticky Information and Monetary Regime Changes

The analysis of monetary explanations of stagflation utilizes the sticky information model of Mankiw and Reis (2002) but modifies this model to allow for the possibility of regime changes as suggested by Barsky and Killian (2002). Specifically, I assume that the monetary authority can induce transitory and potentially long-lasting changes in its operating instrument, where long-term changes represent *monetary regime changes*. These regime changes come at random intervals and can take on a continuum of sizes. Price-setters, unable to distinguish between the transitory shocks and the regime changes, must filter the available information in order to make forecasts for use in price-setting. This modification introduces a new set of dynamics to the literature on models of sticky information.

A Sticky Information Model

The key assumption underlying the sticky information model is that information acquisition is costly and because of this price-setters have incentives to update their information infrequently. This contrasts with sticky price models, which assume that price adjustment is costly, thus giving firms incentives to change prices infrequently.[5] While Calvo (1983)-style updating makes the models equally tractable, the sticky information model does not share the disinflationary booms or the lack of inflation inertia that arise from the standard New Keynesian Phillips curve in the absence of ad hoc assumptions on pricing (see, e.g., Ball 1994, Nelson 1998,

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[4] One may wish to consider a broader definition of stagflation, so that more of the 1970s are considered to be stagflationary. The criteria set out seek to capture the "heart" of what constitutes stagflation.

[5] In a case study of a large industrial manufacturer, Zbaracki et al. (2004) find that managerial costs—including information acquisition, decision-making, and communication—are almost an order of magnitude larger than explicit menu costs of changing prices. Carroll (2003), Mankiw and Reis (2003), Mankiw et al. (2004), Andrés et al. (2005), Kiley (2005), and Khan and Zhu (2006) present empirical evidence of sticky information.

and Mankiw and Reis 2002).[6] In addition, Andrés et al. (2005) show that the sticky information model satisfies the Natural Rate Hypothesis for a broader set of conditions than models that rely on sticky prices and Calvo price-setting.

The sticky information model consists of identical, monopolistically competitive firms. A firm's desired price at time t, p_t^*, is

$$p_t^* = p_t + \alpha y_t, \tag{3.1}$$

where p_t is the aggregate price level and y_t is the output gap. (All variables are in natural logs, and firm-specific subscripts are omitted since firms are identical.) Normalizing the (log) natural rate of output to zero, the latter term is also output.

Because it is costly to acquire new information, firms do so infrequently. For tractability, the model assumes that each period a fraction λ of firms update their information. This probability is independent of a firm's information-updating history.

The model has three key equations. First, unlike typical sticky price models, all firms are able to set a different price at time t from the price they set at time $t-1$. However, the fraction $1-\lambda$ do so using their old information about the currently optimal price. The expectation that is relevant for the firms using old information is the time $t-i$ expectation of the time t optimal price: a firm that last updated its information $i>0$ periods ago sets the time t price $\hat{p}_{t,i} = E_{t-i}\left(p_t^*\right)$, where p_t^* is the firm's desired price from (3.1).[7] The fraction λ of firms that update their information at time t set $\hat{p}_{t,0} = p_t^*$. Second, the aggregate price level is the average of all individual firms' prices.

$$p_t = \lambda \sum_{i=0}^{\infty} (1-\lambda)^i \, \hat{p}_{t,i}$$

Third, combining these two equations with the equation for a firm's desired price (3.1) yields the sticky information Phillips curve

$$\pi_t = \frac{\alpha\lambda}{1-\lambda} y_t + \lambda \sum_{i=0}^{\infty} (1-\lambda)^i E_{t-1-i}\left(\pi_t + \alpha\Delta y_t\right), \tag{3.2}$$

where Δy_t is output growth or, alternatively, the change in the output gap.

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[6] Trabandt (2003), Keen (2005), and Coibion (2006) show the sensitivity of inflation inertia in the sticky information model to real rigidities and a DSGE setting.

[7] This is similar in spirit to expected market-clearing price models, but now only a fraction of agents use a particular set of expectations. This helps remedy the deficiencies of these models as identified in Nelson (1998).

For simplicity, aggregate demand takes a quantity theoretic form

$$m_t = p_t + y_t. \tag{3.3}$$

With constant log velocity normalized to zero, m_t can be interpreted as money.

Modeling the Monetary Authority

The monetary authority controls the money supply through the money growth equation

$$\Delta m_t = M_t + \rho \Delta m_{t-1} + \varepsilon_t. \tag{3.4}$$

Transitory changes to its operating instrument, which are persistent by virtue of the parameter $\rho \in (0,1)$, are denoted by ε_t. These are modeled as i.i.d., normally distributed shocks with mean zero and variance σ_ε^2. The term M_t is the *monetary regime* as of time t, since $M_t(1-\rho)^{-1}$ represents the monetary authority's "long-run" money growth target at that time. I allow for the possibility that the central bank may change the "long-run" target by specifying

$$M_t = \rho_M M_{t-1} + \xi_t. \tag{3.5}$$

Changes in M_t are thus *monetary regime changes*.[8] I assume that regime changes are potentially long-lasting—and therefore distinguishable from transitory shocks—by considering $\rho_M \in (\rho,1]$.

On average, one would assume that a regime change may be a rare occurrence, and when a regime change does occur it is of uncertain size. Thus I model the shock ξ_t as consisting of two parts, $\xi_t=\zeta_t*\gamma_t$. The random variable ζ_t determines whether a regime change occurs or not. This can be modeled as a Poisson process with mean and variance β. The size of the regime change is determined by γ_t, which is normally distributed with mean zero and variance σ_γ^2. Both variables are identically distributed and independent—of each other and of the transitory shocks.

All firms know the structural parameters ρ, ρ_M, β, σ_ε^2, and σ_γ^2. The money growth rate Δm_t along with its entire history is observable by all firms who update their information at time t

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[8] This is related to the suggestion in Barsky and Kilian (2002) that the breakdown of the Bretton Woods system of fixed exchange rates constituted a monetary regime change, which ushered in a period of more expansionary monetary policy and played a central role in the U.S. stagflation of the 1970s. Andolfatto and Gomme (2003) present a similar model of monetary regime changes which relies upon a two-state Markov process. In that case, regime changes could still be a rare occurrence, but they would not be of uncertain size. De facto, long-run changes in money growth equate to long-run changes in inflation (and, implicitly, the monetary authority's target for it). Allowing for shifts in monetary policymakers' long-run inflation objectives is consistent with U.S. evidence presented by Kozicki and Tinsley (2001a, 2001b).

or later. In the majority of the analysis, however, I assume that only the monetary authority knows the monetary regime M_t with certainty. If $\beta=0$, then all firms know the monetary regime—and, for that matter, that the regime will never change. In this case, firms that see shocks know with certainty that they are transitory. When $\beta>0$, firms observe the difference between Δm_t and $\rho\Delta m_{t-1}$,

$$\Delta m_t - \rho\Delta m_{t-1} = x_t = M_t + \varepsilon_t, \tag{3.6}$$

but they are unable to distinguish between individual elements of x_t.

Learning by Firms

Forecasting future money growth is important for price-setters since a firm that last updated its information $i>0$ periods ago sets its price today to $\hat{p}_{t,i} = (1-\alpha)E_{t-i}p_t + \alpha E_{t-i}m_t$. Because of this, knowing the monetary regime is crucial. When the central bank's actions are not completely transparent, firms must learn about the nature of the monetary regime.

Given (3.4), (3.5), and the structure of the shocks, firms use a signal extraction problem to form projections over the paths of future variables. I adapt this to the firms' problem in the Mathematical Appendix. Using the fact that the money growth process in MA(∞) form is

$$\Delta m_t = \sum_{i=0}^{\infty} \rho^i x_{t-i}, \tag{3.7}$$

there I conjecture and prove that inflation in the sticky information model takes the form

$$\pi_t = \sum_{i=0}^{\infty} \delta_i x_{t-i}. \tag{3.8}$$

With (3.7), (3.8), and (3.3), one is able to calculate impulse responses for inflation and the output gap and simulate the model.

Calibration and Impulse Responses for Transitory Shocks and Regime Changes

To illustrate the interaction between learning and the sticky information model with transitory shocks and regime changes, Figure 5 through Figure 8 present impulse responses to the two shocks. Prior to time $t=0$, the economy is in a steady state with zero money growth

($M_{-1} = 0$). The parameters are calibrated as follows. To ensure stationarity and make regime changes long-lasting but not permanent per se, I calibrate ρ_M to 0.999. I initially allow the probability of a shock to the monetary regime, where β is the mean of the Poisson process governing regime change arrivals, to take on one of two values: β=0 (no regime changes are possible) and β=0.025 (a regime change occurs approximately once every ten years).[9] The rate of firm information updating (λ) is set to 0.25, so that firms update their information once per year on average (see, e.g., Khan and Zhu 2006). The measure of real rigidity, in the spirit of Ball and Romer (1990), is set so α=0.1, as in Mankiw and Reis (2002).

The remaining parameters relate to the persistence and variability of the money growth process. The AR coefficient in the money growth equation, ρ, is 0.56. The standard deviation of the transitory shocks, σ_ε, is 0.006. With a quarterly model, a one standard deviation transitory shock increases money growth by 2.4 percentage-points on an annual basis in the quarter in which it occurs. The standard deviation of the size of the regime-change shocks, σ_γ, is 0.003. Thus a one standard deviation regime change causes money growth to rise 1.2 percentage-points in the quarter in which it occurs. Given the values of ρ and ρ_M, money growth subsequently accelerates further for several quarters, peaking at slightly above 2.75 percentage-points before beginning a very slow descent (due to the extreme persistence of ρ_M).[10]

Figure 5 depicts the case in which no regime changes are possible (β=0) and money growth increases by one standard deviation at time t=0. This is a "known" transitory change in money growth that will persist for a short time. (Alternatively, this also describes the case in which β>0 but firms can distinguish between transitory shocks and regime changes.) As in Mankiw and Reis (2002), the sticky information model exhibits inflation inertia: inflation follows a hump shape and peaks seven quarters after the monetary expansion. The output gap also follows a hump-shaped pattern, peaking three quarters after the shock.

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[9] This paper considers exogenous changes to the monetary regime. An example of such an exogenous shock might be a change in the Federal Reserve Chairmanship to a chairman who has a different target money growth rate than his predecessor. During the period 1959–2002, there were five different chairmen for an average tenure of about nine years. Using Canadian data, Andolfatto and Gomme (2003) estimate that average regimes similar to those above last ten years. In subsequent sections, I consider other values for this parameter as well.

[10] Given the calibrations ρ_M=0.999 and β=0.025, the values for ρ, σ_ε, and σ_γ were estimated via simulated method of moments based upon the empirical standard deviation and autocorrelations of M2 money growth in U.S. data from 1959 through 2002. While changes in β (below) would produce different estimates, these parameters were kept for the sake of comparison with this baseline set of parameters.

Allowing for the possibility that the monetary regime might change has dramatic effects, even if the economy experiences the same transitory shock as above. In Figures 6 and 7, the probability that the monetary regime changes in a given quarter is β=0.025. More important, however, is the fact that now agents cannot immediately distinguish between transitory shocks to the money growth rate and regime changes, and they must learn about the nature of the shock. These are "unknown" shocks, in contrast with the "known" transitory shock from Figure 5.

In Figure 6, money growth experiences a transitory positive one standard deviation shock that is unknown to agents. This shock is the same size as that in Figure 5. Initially, the responses of inflation and the output gap in the model appear similar to those when the shock is known to be transitory: the output gap peaks three quarters after the shock, and the inflation rate increases gradually and peaks later (after eight quarters in this case). However, shortly thereafter the responses diverge and the output gap exhibits oscillatory behavior—so that the output gap turns negative twelve quarters after the monetary expansion.[11]

Explaining this phenomenon is relatively simple. Recall that the transitory expansionary shocks to money growth are identical in Figures 5 and 6. The responses of inflation, however, are different. Inflation rises by a maximum of 0.44 percentage-point after seven quarters when the shock is known to be transitory but 0.61 percentage-point after eight quarters when the duration of the shock is not known. In effect, firms in the unknown-shock case "hedge their bets" regarding the type of shock they have experienced. In a sticky information environment, firms that update their information following the shock place a positive probability on the fact that M_t changed, which in turn affects their expectations over future optimal prices until they next update their information. It is only over time—as more price-setters update their information *and* have more observations with which to form forecasts—that agents begin to learn that it was most likely a transitory shock. The result is that inflation overshoots where it should have been, leading to inflation that is relatively high compared with the case in which the shock is known to be transitory. For the same rate of money growth, a rate of inflation that is too high implies that output growth, and therefore the output gap, must be too low. Thus we see the oscillatory behavior of the output gap.

Figure 7 presents the behavior of inflation and the output gap in response to a one standard deviation increase in the monetary regime M_t at time t=0. Because of the AR term in

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[11] This is not due to money growth, which is above its steady-state level and is converging monotonically toward it.

(3.4), money growth initially jumps and then accelerates further for several quarters, peaking at slightly less than 2.75% before beginning a very slow descent (due to the extreme persistence of ρ_M). There is no announcement or clarification on the part of the monetary authority, so firms do not know if this is a transitory shock or a regime change. For comparison, Figure 8 depicts the responses to the same shock when the actions of the central bank are transparent and firms realize that the monetary regime has changed.

The increase in M_t leads to an expansion which is much longer in the case of an unknown shock than in the case of a known shock. Again, the intuition behind this result is clear. It is only with time that firms learn about the duration of the shock. Following the regime change, firms which acquire new information believe with some positive probability that money growth simply experienced a transitory shock. The prices these firms set will therefore be lower than they would have been if information about the monetary regime were known with certainty. As a result, inflation does not rise as quickly as it should and a long expansion ensues.

A close examination of the impulse responses reveals why the combination of the sticky information model and indistinguishable transitory shocks and long-lasting regime changes can yield stagflation. From Figure 6, inflation's overshooting causes the output gap to be falling—and turn negative—while (inertial) inflation is still high. As set out in the previous section, this is classic stagflation. In addition, from Figure 7 we see that a regime change under learning leads to a longer expansion and a slower inflation response than the case in which the regime change is known. In a stochastic environment, it is thus conceivable that a contractionary (unknown) regime change, starting from a point in which inflation was already above average, might produce stagflation more often than if the regime change were known with certainty.

IV   Stagflation in the Simulations

I simulate the model from Section III and apply the stagflation algorithm to the simulated data to determine whether the model can consistently generate stagflation similar to the U.S. experience. When only transitory shocks to money growth are possible, the model is incapable of producing stagflation on a consistent basis. When monetary regime changes are possible, the model economy regularly experiences at least one stagflationary episode. I show that this result is not

dependent upon actual changes to the monetary regime: the uncertainty surrounding monetary shocks in this environment is enough to engender stagflation.

Simulation Results

Since the data used to construct the stagflation algorithm considered the period 1959–2002, the model is simulated for 176 quarters to match this time frame. To ensure that the results are not dependent upon initial starting values, the model is simulated for 100 preliminary quarters prior to the 176 of interest. Before that time, the economy was in its steady state. All calibrations are the same as those used in Section III, and the results are based upon 1,000 simulations. While the parameter governing the arrival of regime changes, β, is varied, the same sets of transitory money growth shocks (ε) and regime change sizes (γ) are used between sets of simulations to limit the effect of different shock realizations.

Table 1 presents simulation results. Consider first the case in which monetary regime changes are not possible ($\beta=0$) and firms know this fact. The results are clear: stagflation is very rare, with only 6% of simulations suffering at least one stagflationary episode. Choosing a larger standard deviation for the exogenous transitory money shocks would better fit the data in terms of the standard deviation of money growth (0.88% in the U.S. data; 0.7% on average in the simulations), but this does not produce more stagflation. Furthermore, while it would increase the standard deviation of inflation (0.62% in the data; 0.31% on average in the simulations), it would also increase the volatility of the output gap which is already higher than in the empirical data (1.55% in the data; 2.48% in the simulations).

Alternatively, consider the baseline case in which $\beta=0.025$, so that on average the monetary regime changes once every ten years. The central bank does not make its policies (in the form of money growth shocks) explicitly known, which requires that firms learn about the nature of the shocks they face through a signal extraction problem. This combination of factors generates stagflation regularly: 76% of the simulations experience at least one stagflationary episode. On average, 3.6 out of the 176 quarters of each simulation fit the stagflationary criteria. If one only considers the 76% of simulations with stagflation, the average number of stagflationary quarters is 4.7. This is very similar to the five stagflationary quarters in the U.S. data during the period 1959–2002. Additionally, the inclusion of monetary regime changes

makes the within-sample standard deviations of money growth and inflation similar to those from the data.

To rule out the possibility that there is something inherently special about this particular β, the Poisson probability governing the arrival of monetary regime changes, I consider other values for this parameter as well. Table 1 presents results for a range of βs such that, at one end of the spectrum, a monetary regime change occurs on average once every 50 years, to the extreme possibility that the regime changes on average once per year. The basic result still holds: even the remote possibility of a monetary regime change is enough to consistently generate stagflation. If the monetary regime changes more frequently, on average, than once every 35 years, there is greater than a 50% probability that stagflation will occur within a given 176-quarter period. Moreover, as regime changes become more likely within a given quarter— i.e., as β increases—the incidence of stagflation increases as well.

The Role of Regime Changes

The positive correlation between the probability of a regime change, β, and the incidence of stagflation suggests two possibilities. First, as β increases, the monetary regime changes more frequently, and it is these regime changes which cause more stagflationary episodes. Alternatively, as β increases, price-setters experience more uncertainty—since a given shock has a greater probability of being a regime change than before—and it is this additional uncertainty which produces more stagflationary episodes. This section supports the latter by showing that regime changes need not occur in order to generate stagflation. The uncertainty caused by the mere possibility of a monetary regime change, and the subsequent learning via a signal extraction problem, are enough to regularly cause the phenomenon.

To assess the role regime changes play, I divide the 1,000 simulations into two groups based upon whether a monetary regime change occurred within the 176 quarters of interest or not. These groups are labeled "One regime" and "Multiple regimes," and Table 2 presents the results from this dichotomization. For most probabilities of a regime change, stagflation is only slightly more likely to occur when the monetary regime changes than when it does not. For the case in which a monetary regime change occurs on average once every ten years, the incidence

of stagflation is virtually the same.[12] While regime changes produce conditions favorable to slightly longer stagflationary episodes, this is suggestive evidence that it is learning about the nature of the monetary shocks—and not monetary regime changes per se—that is responsible for consistently generating stagflation in this model.

This result is related to two recent studies of stagflation.[13] In one, Barsky and Kilian (2002) suggest that the breakdown of the Bretton Woods system of fixed exchange rates constituted a shift in the monetary regime. This shift ushered in a period of alternating expansionary and contractionary (or go-stop) monetary policy which the authors argue was a causal factor in the U.S. stagflation of the 1970s and early 1980s.[14] Using a stylized model in which agents are slow to "wake up to" a regime change, Barsky and Kilian (2002) show that a go-stop sequence of shocks can generate stagflation similar to the U.S. experience.

In a second paper, Orphanides and Williams (2005a) model a situation in which agents form inflation expectations via a perpetual learning mechanism: finite memory least squares. Such an approach is particularly useful in the midst of structural shifts (Evans 2005), though such shifts that would require the use of or benefit from perpetual learning are not modeled by the authors. Instead, Orphanides and Williams (2005a) subject their model to a particular sequence of inflationary shocks—potentially resulting from either the demand or supply side of the economy, but intended to resemble events buffeting the U.S. economy during the 1970s— and show that stagflation can result in such an environment if the monetary authority is too dovish on inflation.[15]

Both papers show that stagflation can result from particular sets of one-time shocks in the spirit of an impulse response—and that supply shocks are not necessary to explain the phenomenon—when agents must effectively learn about aspects of the economy. In this paper, I make regime changes a stochastic component of the economy and show that stagflation can

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[12] In the table, all simulations when β=0.05 contain regime changes. Running a counterfactual experiment in which β is still set to 0.05 but the regime changes are suppressed—i.e., ζ_t is forced to zero for all t—produces stagflation in 87% of the simulations, a slightly higher incidence than when the regime is allowed to (and does) change.

[13] For other papers on the connection between money and stagflation, see also Loyo (1999), Christiano and Gust (2000), Nelson and Nikolov (2004), and Orphanides and Williams (2005b). Brunner et al. (1980) and Cukierman (1984, chapter 9) examine the connection between permanent and transitory shock confusion and stagflation in the context of a productivity shock.

[14] To a lesser extent, Blinder (1979) and Bruno and Sachs (1985) identify go-stop monetary policy as one of the many shocks buffeting the U.S. economy during the 1970s. Helliwell (1988) acknowledges that go-stop monetary policy could cause stagflation in general.

[15] Whether the Federal Reserve was hawkish or dovish during the 1970s is open to debate; see Clarida et al. (2000) and Orphanides (2000).

occur regularly in a dynamic setting. The results that I present do not require taking a position on whether the monetary authority is dovish or hawkish with respect to inflation. Additionally, I find that a monetary regime change itself need not occur to generate stagflation.

Explaining why stagflation consistently occurs in the model is aided by Table 1 and the impulse responses (Figure 5 through Figure 7). Table 1 indicates that increases in the probability that a monetary regime change β will occur in a given quarter lead to more stagflation. The larger is β, the more volatile are the inflation rate and the output gap within the sample period. Naturally, part of the increasing volatility of inflation can be explained by the fact that money growth, and thereby inflation, becomes more volatile when the regime changes. The other part, however, is a consequence of the firm's learning problem.

Immediately following a shock to money growth, price-setters who update their information cannot be sure whether it is a transitory change or a regime shift. As a result, they effectively "hedge their bets" and place some positive probability on each event when setting their prices. It is only with the passing of time—when agents have more time-series data on money growth *and* more agents have updated their information—that most price-setters are able to determine which event occurred. Consequently, the inflation rate in the immediate aftermath of a shock falls between what it would be if the shock were known to be transitory and if it were known to be a regime shift. The greater is β, the greater is the probability that a regime change with long-lasting effects on money growth occurred, and the more closely the inflation response will resemble that experienced following a known regime change.

If it turns out that the shock was only transitory, however, inflation will overshoot where it "should be" given the true money growth shock. Over time, price-setters will learn this; however, inflation's overshooting combined with its inertia increase the volatility of the output gap. The greater is β, the greater is inflation's overshooting, and the greater the volatility of the output gap. The volatility of the output gap when the regime can change, coupled with the inflation inertia imparted by the model, lead to conditions conducive to the emergence of monetary stagflation, even in the absence of an actual regime change.[16]

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[16] See Figure 6, where a single unknown transitory shock causes inflation to be persistently high while the output gap turns negative and is falling in quarters 11–13.

The Role of Central Bank Transparency and Stability

To examine the role that the central bank's lack of transparency plays, I alter the model in Section III to consider the case in which the monetary authority is completely transparent: price-setters are not only able to observe the overall growth of the money supply, but they are also able to observe its individual components—the monetary regime M_t and transitory shocks ε_t. This might be the case if the central bank's policy decisions were implemented and completely described to (and believed by) price-setters concurrently. Because shocks and regime changes are both stochastic, however, there are no announcements of future events. With this transparency, the models are re-simulated using the same shocks as were previously used and the incidence of stagflation is reported in the "Transparent Central Bank" columns of Table 3.

Making the monetary policies transparent reduces the likelihood that stagflation will occur for all $\beta>0$. (When $\beta=0$, the central bank's policies are transparent and stable, in that long-lasting changes in the money growth rate—i.e., monetary regime changes—do not occur.) When firms perfectly observe monetary policy, the simulated economies suffer from stagflation fifteen to twenty percentage-points less often than the case in which price-setters have to learn about changes to money growth. The greater accuracy in interpreting the money growth rate allows firms that update their information to set more accurate prices, thereby reducing the variance of the inflation rate and, by extension, the variance of the output gap. This also eliminates the overshooting phenomena elucidated above.

Now, most stagflation coincides with the presence of regime changes. A sudden contractionary regime change leads to a sharp recession and a slightly more gradual fall in the inflation rate (the mirror image of Figure 8). Had the economy previously been in a situation of relatively high inflation (due to, say, an earlier series of positive transitory money growth shocks) with output near the natural rate, such a shock—even when fully perceived—can cause stagflation. These findings support the idea that central bank transparency can help to reduce the incidence of poor macroeconomic performance as embodied by monetary stagflation. Furthermore, monetary authorities who eschew long-lasting regime changes in favor of more stable policies greatly reduce the probability of stagflation arising from monetary factors.

<u>The Role of Inflation Inertia</u>

As calibrated above, the sticky information model induces substantial inertia into the inflation process. With α=0.1, the maximal inflation response occurs seven quarters after a known transitory shock. Keen (2005) and Coibion (2006) note, however, that this inflation inertia is directly related to the amount of real rigidity within the model: the greater the real rigidity (the smaller is the parameter α), the greater is the inflation inertia. By varying α, I consider how variations in inflation inertia affect the incidence of stagflation.

Figure 9(a) shows that greater amounts of inflation inertia (as measured by the length of time it takes for the inflation rate to reach its maximal response following a known transitory shock) are correlated with more stagflation. For the range of inflation inertia suggested by empirical studies (e.g., Nelson 1998 and Estrella and Fuhrer 2002), stagflation occurs at least once in more than 80% of simulations. Sticky information models with little inflation inertia cannot regularly generate stagflation in the presence of regime changes. This is true whether price-setters need learn about the regime changes or not. Intuitively, inflation's rapid response to a money shock reduces output gap movements and prevents the combination of overshooting and inflation inertia that produces the oscillatory behavior seen in Figure 6. This causes inflation and the output gap to co-move positively, in contrast to the negative co-movement characterizing stagflation. Thus sufficient inflation inertia is a key ingredient in generating stagflation.[17]

<u>Stagflation in a Sticky Price Model</u>

To assess what role—if any—sticky information plays in generating stagflation, I consider what would occur if the monetary authority were unchanged but inflation were instead determined by a hybrid New Keynesian Phillips curve

$$\pi_t = \theta y_t + (1-\Omega)\pi_{t-1} + \Omega E_t \pi_{t+1}. \tag{4.1}$$

(The Mathematical Appendix provides details of the underlying model.) For comparison with the sticky information model, the sticky price model is calibrated to generate an identical amount

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[17] Varying the other parameter values (λ, ρ, σ_γ^2, and σ_ε^2) produces an incidence of stagflation similar to that presented in the paper. Parameter combinations which fail to generate much stagflation tend to require frequent information updating (e.g., λ=0.5, which also implies little inflation inertia) and small signal-to-noise ratios (e.g., $\sigma_\gamma^2 / \sigma_\varepsilon^2 \approx 0.1$).

of inflation inertia. Table 4 presents analogous results to Table 3, and Figure 9(b) varies the amount of forward-looking behavior in (4.1) to generate the analog of Figure 9(a).

In general, the table and figure show that stagflation is not an artifact of the sticky information model. When regime changes occur on average once every ten years and price-setters cannot immediately distinguish between transitory shocks and regime changes, stagflation occurs in 69% of simulations, compared with 76% of sticky information simulations. Also similar to the sticky information model, the greater is the degree of inflation inertia, the higher is the probability that stagflation will occur within a given simulation.

The only notable difference between the two specifications comes when the central bank is transparent and there is little or no inflation inertia. In the sticky price model, this occurs when the Phillips curve takes on the standard form $\pi_t = \theta y_t + E_t \pi_{t+1}$. The fact that central bank transparency leads to a higher incidence of stagflation is the exact opposite of the "disinflationary booms" criticism leveled against this model: these are "expansionary stagflations." Following a known expansionary regime change, money growth initially increases but then increases still more in the near term because of (3.4). In the sticky price model with transparency, agents anticipate the secondary increase and set their prices too high immediately following the expansionary regime change (since it may be some time before they can adjust again). This causes inflation to exceed money growth temporarily, implying that output must fall. Had the simulated economy been near the natural rate of output, this burst of inflation coupled with a falling output gap bears the hallmarks of stagflation.

V   Conclusion

This paper finds that a dynamic, stochastic model with purely monetary shocks can consistently generate stagflation. The form of stagflation in the simulated data matches key characteristics of the U.S. experience during the 1970s and early 1980s, based upon a close inspection of the historical record.

The mechanism driving this result is the ability of the monetary authority to induce both transitory and long-lasting changes to its operating target, where the latter can be termed "regime changes." I show how the inflation and output dynamics of a sticky information model are affected when price-setters cannot distinguish between these shocks. Even when regime changes

are a rare occurrence, stagflation occurs regularly in model simulations. If the monetary regime changes on average once every ten years, stagflation occurs in 76% of model simulations. The intuition for this result is simple: the learning process required when transitory shocks and regime changes are indistinguishable induces volatility into the output gap which, when combined with inertial inflation, produces conditions conducive to the appearance of stagflation.

To isolate the factors at play in the simulations, I consider several exercises. In the first, I show that regime changes per se are not requisite to generate stagflation. The uncertainty associated with the learning mechanism is enough to produce stagflation even in the absence of actual regime changes. In a second exercise, I demonstrate that a more transparent central bank that allows price-setters to distinguish between transitory shocks and regime changes would reduce the incidence of poor macroeconomic performance as embodied by monetary stagflation. Nevertheless, some stagflation continues to occur, in particular related to monetary regime changes. In a third exercise, I show that inflation inertia plays an important role in generating stagflation. Finally, I show that the results are not an artifact of the sticky information model: a hybrid New Keynesian Phillips curve with a suitable amount of inflation inertia can consistently generate stagflation as well.

Despite these exercises, this paper leaves open several questions. The first regards the stagflation associated with regime changes that occurs when the central bank's actions are transparent. In this paper, regime changes are stochastic events that are unknown to price-setters and the central bank beforehand. However, if the central bank were to announce regime changes prior to implementing them, it is possible that the incidence of monetary stagflation could be reduced even further.[18] Another question concerns the stagflation algorithm proposed for this paper. While this algorithm was based upon a close investigation of the U.S. historical record, would it also be useful for identifying stagflationary episodes in other countries? I leave exploration of these possibilities for future research.

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[18] Cf. Mankiw and Reis (2002), where the output loss following an announced disinflation—similar in spirit to a contractionary regime change in this paper—is trivial compared with the case in which the change is unanticipated.

VI   Mathematical Appendix

This section derives the inflationary process for the sticky information model given by equation (3.8). I also show how the signal extraction problem factors into the analysis.

Mankiw and Reis (2002) show that the sticky information Phillips curve is

$$\pi_t = \frac{\alpha\lambda}{1-\lambda} y_t + \lambda \sum_{i=0}^{\infty} (1-\lambda)^i E_{t-1-i}\left(\pi_t + \alpha\Delta y_t\right), \tag{6.1}$$

where Δy_t is output growth. Aggregate demand takes a quantity theoretic form

$$m_t = p_t + y_t. \tag{6.2}$$

Substituting for y_t and Δy_t in (6.1) yields

$$\pi_t = \frac{\alpha\lambda}{1-\lambda}(m_t - p_t) + \lambda \sum_{i=0}^{\infty} (1-\lambda)^i E_{t-1-i}\left[\alpha\Delta m_t + (1-\alpha)\pi_t\right]. \tag{6.3}$$

The money supply rule is given by

$$\Delta m_t = M_t + \rho\Delta m_{t-1} + \varepsilon_t, \quad M_t = \rho_M M_{t-1} + \xi_t. \tag{6.4}$$

This implies money supply can be written in two MA(∞) forms, each of which is a function of $x_t = \Delta m_t - \rho\Delta m_{t-1} = M_t + \varepsilon_t$.

$$\Delta m_t = \sum_{i=0}^{\infty} \rho^i x_{t-i}, \quad m_t = \sum_{j=0}^{\infty}\sum_{i=0}^{\infty} \rho^i x_{t-i-j} \tag{6.5}$$

The solution to the sticky information model employs the method of undetermined coefficients. I conjecture

$$\pi_t = \sum_{i=0}^{\infty} \delta_i x_{t-i}, \quad p_t = \sum_{j=0}^{\infty}\sum_{i=0}^{\infty} \delta_i x_{t-i-j}. \tag{6.6}$$

To find the δ_i coefficients, substitute for Δm_t, m_t, π_t, and p_t in (6.3).

$$\sum_{i=0}^{\infty} \delta_i x_{t-i} = \frac{\alpha\lambda}{1-\lambda}\left[\sum_{j=0}^{\infty}\sum_{i=0}^{\infty}\left(\rho^i - \delta_i\right)x_{t-i-j}\right] + \lambda\sum_{i=0}^{\infty}(1-\lambda)^i\left\{\sum_{j=0}^{\infty}\left[\alpha\rho^j + (1-\alpha)\delta_j\right]E_{t-1-i}x_{t-j}\right\} \tag{6.7}$$

When $i+1 \leq j$, $E_{t-1-i}x_{t-j} = x_{t-j}$; thus we need only deal with expectations when $i+1 > j$.

Since x_{t-j} is composed of ε_{t-j}, which is white noise, and M_{t-j}, this equates to forecasting M_{t-j} with information known as of time $t-1-i$. I assume that this forecast is made

using the Kalman filter; see Hamilton (1994). Rewriting (6.4) in terms of its state-space representation, the one-period-ahead forecast of M_t—i.e., $E_{t-1}x_t = \hat{M}_{t|t-1}$—is

$$\hat{M}_{t|t-1} = \rho_M \hat{M}_{t-1|t-2} + \mathrm{K}_{t-1}\left(x_{t-1} - \hat{M}_{t-1|t-2}\right), \tag{6.8}$$

where $\mathrm{K}_{t-1} = \rho_M \mathrm{P}_{t-1|t-2}/(\mathrm{P}_{t-1|t-2} + \sigma_\varepsilon^2)$. The associated mean-squared error is

$$\mathrm{P}_{t|t-1} = \rho_M^2\left[\mathrm{P}_{t-1|t-2} - \mathrm{P}_{t-1|t-2}^2\left(\mathrm{P}_{t-1|t-2} + \sigma_\varepsilon^2\right)^{-1}\right] + \sigma_\xi^2. \tag{6.9}$$

Since $\xi_t = \zeta_t * \gamma_t$ is the product of two independent random variables—ζ is Poisson with mean and variance β and γ is normal with mean zero and variance σ_γ^2—then $\sigma_\xi^2 = (\beta + \beta^2)\sigma_\gamma^2$. Because (6.9) only depends upon model parameters and its own history, I set

$$\mathrm{P} = \mathrm{P}_{t|t-1} = \mathrm{P}_{t-1|t-2} = 0.5\left\{\sigma_\xi^2 + \sigma_\varepsilon^2\left(\rho_M^2 - 1\right) + \sqrt{\left[\sigma_\xi^2 + \sigma_\varepsilon^2\left(\rho_M^2 - 1\right)\right]^2 + 4\sigma_\xi^2\sigma_\varepsilon^2}\right\} \ \forall t.$$

This implies $\mathrm{K} = \rho_M\mathrm{P}/(\mathrm{P} + \sigma_\varepsilon^2)$. Combining this fact with (6.8), one finds

$$E_{t-1-i}x_{t-j} = \rho_M^{i-j}\mathrm{K}\sum_{\ell=0}^{\infty}\left(\rho_M - \mathrm{K}\right)^\ell x_{t-\ell-i-1}. \tag{6.10}$$

Substitute (6.10) into (6.7) where necessary to produce the following.

$$\sum_{i=0}^{\infty}\delta_i x_{t-i} = \frac{\alpha\lambda}{1-\lambda}\left[\sum_{j=0}^{\infty}\sum_{i=0}^{\infty}\left(\rho^i - \delta_i\right)x_{t-i-j}\right] + \lambda\sum_{i=0}^{\infty}(1-\lambda)^i\left\{\left(\sum_{j=0}^{i}\left[\alpha\rho^j + (1-\alpha)\delta_j\right]\right)*\right.$$
$$\left.\left(\rho_M^{i-j}\mathrm{K}\sum_{\ell=0}^{\infty}\left[\rho_M - \mathrm{K}\right]^\ell x_{t-\ell-i-1}\right) + \left(\sum_{j=i+1}^{\infty}\left[\alpha\rho^j + (1-\alpha)\delta_j\right]x_{t-j}\right)\right\}$$

Matching coefficients on both sides for x_{t-i}, $i=0,1,2,\ldots$, yields the set of δ_is needed from (6.6).

$$\delta_i = \left[1 + \frac{\alpha\lambda}{1-\lambda} - (1-\alpha)\left(1 - [1-\lambda]^i\right)\right]^{-1} * \left\{\frac{\alpha\lambda}{1-\lambda}\left[\rho^i + \sum_{j=0}^{i-1}\left(\rho^j - \delta_j\right)\right] + \right.$$
$$\left.\alpha\rho^i\left[1 - (1-\lambda)^i\right] + \lambda\mathrm{K}\sum_{j=0}^{i-1}(1-\lambda)^j\left(\rho_M - \mathrm{K}\right)^{i-j-1}\sum_{\ell=0}^{j}\left[\alpha\rho_M^{j-\ell}\rho^\ell + (1-\alpha)\delta_\ell\right]\right\}, i = 0,1,2,\ldots$$

The above solution covers the case in which price-setters are unable to distinguish between transitory and permanent shocks to money growth. Suppose, however, that the monetary authority is transparent and its actions can be perfectly observed; i.e., firms can observe the components of Δm_t—M_t and ε_t—and their entire histories. Money growth and the money supply can be written in MA(∞) form

$$\Delta m_t = \sum_{i=0}^{\infty} \rho^i \left(M_{t-i} + \varepsilon_{t-i} \right), \quad m_t = \sum_{j=0}^{\infty}\sum_{i=0}^{\infty} \rho^i \left(M_{t-i-j} + \varepsilon_{t-i-j} \right).$$

This changes the conjectured inflation and price processes in the sticky information model to

$$\pi_t = \sum_{i=0}^{\infty} \left(\Upsilon_i M_{t-i} + X_i \varepsilon_{t-i} \right), \quad p_t = \sum_{j=0}^{\infty}\sum_{i=0}^{\infty} \left(\Upsilon_i M_{t-i-j} + X_i \varepsilon_{t-i-j} \right).$$

Substituting these conjectures into (6.3), and assuming that expectations are formed rationally based upon (6.4) and the assumptions made for ε_t, ζ_t, and γ_t, one can solve for the coefficients.

$$\Upsilon_i = \left[1 + \frac{\alpha\lambda}{1-\lambda} - (1-\alpha)\left(1 - \left[1-\lambda\right]^i\right) \right]^{-1} * \left\{ \frac{\alpha\lambda}{1-\lambda}\left[\rho^i + \sum_{j=0}^{i-1}\left(\rho^j - \Upsilon_j\right) \right] + \alpha\rho^i\left[1 - (1-\lambda)^i \right] + \right.$$

$$\left. \lambda(1-\lambda)^{i-1}\sum_{j=0}^{i-1} \rho_M^{i-j}\left[\alpha\rho^j + (1-\alpha)\Upsilon_j \right] \right\}, \quad i = 0,1,2,...$$

$$X_i = \left[1 + \frac{\alpha\lambda}{1-\lambda} - (1-\alpha)\left(1 - \left[1-\lambda\right]^i\right) \right]^{-1}\left\{ \alpha\rho^i\left[1 - (1-\lambda)^i \right] + \frac{\alpha\lambda}{1-\lambda}\left[\rho^i + \sum_{j=0}^{i-1}\left(\rho^j - X_j\right) \right] \right\}, \quad i = 0,1,2,...$$

The hybrid New Keynesian Phillips curve is a modification of Galí and Gertler (1999). A fraction λ of firms have the opportunity to change their prices each period, and of those updating firms a fraction ω are forward-looking and set price p_t^F. The remaining firms set their prices by the rule-of-thumb $p_t^B = \bar{p}_{t-1} + \pi_{t-1}$, where $\bar{p}_{t-1} = \omega p_{t-1}^F + (1-\omega)p_{t-1}^B$. For comparison with the sticky information model, I ignore discounting and assume that the static optimal price at time t is given by (3.1) (which naturally may differ from the optimal reset price of a forward-looking firm). This model yields the hybrid New Keynesian Phillips curve

$$\pi_t = \theta y_t + (1-\Omega)\pi_{t-1} + \Omega E_t \pi_{t+1}, \quad \theta = \frac{\omega\alpha\lambda^2}{2-\lambda-\omega}, \quad \Omega = \frac{1-\lambda}{2-\lambda-\omega}. \tag{6.11}$$

Obtaining the same amount of inflation inertia in this sticky price model as in the sticky information model, in response to a known transitory shock, requires calibrating $\omega=0.3$.

The model is solved similar to the method above and in Mankiw and Reis (2002). Equation (6.11) can be rewritten in terms of p_t as a cubic in the forward operator and factored as

$$(F - \eta_1)(F - \eta_2)(F - \eta_3)L^2 E_t p_t = \frac{\alpha\omega\lambda^2}{\lambda-1} E_t m_t,$$

where F is the forward operator, L is the lag operator, and $\eta_1 > 1$ and $\eta_2, \eta_3 < 1$ are the roots of the polynomial. This implies that

$$p_t = (\eta_2 + \eta_3)\, p_{t-1} - \eta_2\eta_3 p_{t-2} + \Theta \sum_{i=0}^{\infty} \eta_1^{-i} E_t m_{t+i}, \quad \Theta = \frac{\alpha\omega\lambda^2}{\eta_1(1-\lambda)} \tag{6.12}$$

When firms cannot distinguish between transitory and permanent shocks, conjecture

$$\pi_t = \sum_{i=0}^{\infty} \phi_i x_{t-i}, \quad p_t = \sum_{j=0}^{\infty}\sum_{i=0}^{\infty} \phi_i x_{t-i-j}. \tag{6.13}$$

Using (6.13) and (6.5), rewrite (6.12) as

$$\sum_{j=0}^{\infty}\sum_{i=0}^{\infty} \phi_i x_{t-i-j} = (\eta_2 + \eta_3)\sum_{j=0}^{\infty}\sum_{i=0}^{\infty} \phi_i x_{t-i-j-1} - \eta_2\eta_3 \sum_{j=0}^{\infty}\sum_{i=0}^{\infty} \phi_i x_{t-i-j-2} + \Theta\sum_{\ell=0}^{\infty} \eta_1^{-\ell} E_t \sum_{j=0}^{\infty}\sum_{i=0}^{\infty} \rho^i x_{t+\ell-i-j}.$$

For $(i+j)\geq\ell$, $E_t x_{t+\ell-i-j} = x_{t+\ell-i-j}$ in the last term. When $(i+j)< \ell$, expectations are formed as above.

Matching coefficients implies the following.

$$\phi_i = (\eta_2 + \eta_3 - 1)\left[\sum_{j=0}^{i-1}\phi_j\right] - \eta_2\eta_3\left[\sum_{j=0}^{i-2}\phi_j\right] +$$

$$\Theta\sum_{j=0}^{\infty}\eta_1^{-j}\left\{\left[\sum_{\ell=0}^{j+i}\rho^\ell\right] + K(\rho_M - K)^i \sum_{\ell=0}^{j-1}\rho_M^\ell \sum_{k=0}^{j-\ell-1}\rho^k\right\}, \quad i = 0,1,2,...$$

When the shocks are distinguishable, conjecture that inflation and the price level are

$$\pi_t = \sum_{i=0}^{\infty}\left(\Phi_i M_{t-i} + \Psi_i \varepsilon_{t-i}\right), \quad p_t = \sum_{j=0}^{\infty}\sum_{i=0}^{\infty}\left(\Phi_i M_{t-i-j} + \Psi_i \varepsilon_{t-i-j}\right).$$

The coefficients are as follows.

$$\Phi_0 = \Theta\sum_{j=0}^{\infty}\eta_1^{-j}\sum_{\ell=0}^{j}\rho_M^\ell \sum_{k=0}^{j-\ell}\rho^k$$

$$\Phi_i = (\eta_2 + \eta_3 - 1)\sum_{j=0}^{i-1}\Phi_j - \eta_2\eta_3\sum_{j=0}^{i-2}\Phi_j + \Theta\sum_{j=0}^{\infty}\eta_1^{-j}\sum_{\ell=0}^{j+i}\rho^\ell, \quad i = 1,2,3,...$$

$$\Psi_i = (\eta_2 + \eta_3 - 1)\sum_{j=0}^{i-1}\Psi_j - \eta_2\eta_3\sum_{j=0}^{i-2}\Psi_j + \Theta\sum_{j=0}^{\infty}\eta_1^{-j}\sum_{\ell=0}^{j+i}\rho^\ell, \quad i = 0,1,2,...$$

VII   Works Cited

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## Figure 1: Annual Data on U.S. Real GDP Growth and Inflation, 1970–83
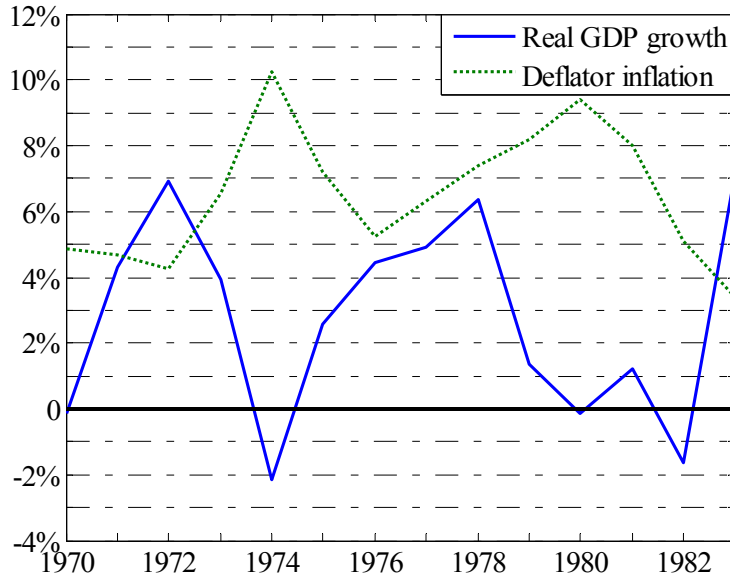
Notes: Annual growth rates are natural log differences of fourth quarter data. Real GDP is in billions of chained 1996 dollars. GDP deflator is chain-type price index with base year 1996. Both series are seasonally adjusted.

Figure 2: Monthly U.S. Unemployment Rate, 1970–83
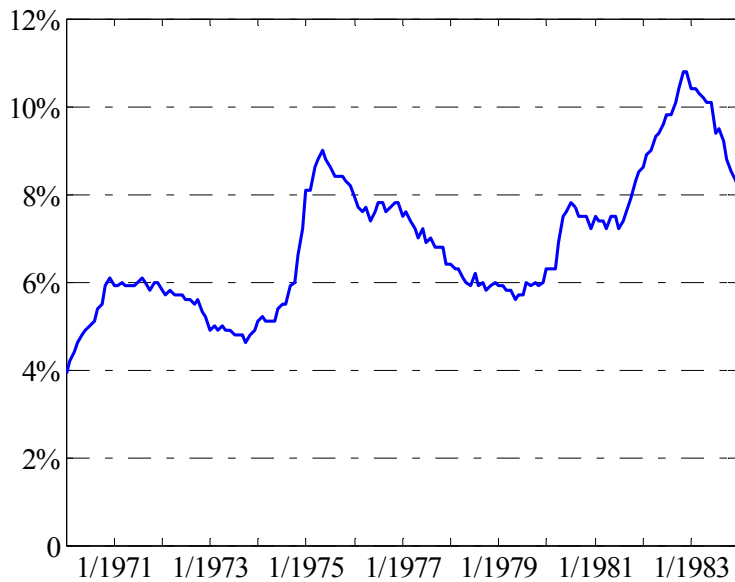
Notes: Civilian unemployment rate, seasonally adjusted.

**Figure 3: Quarterly Data on the U.S. Output Gap and Inflation, 1970–83**
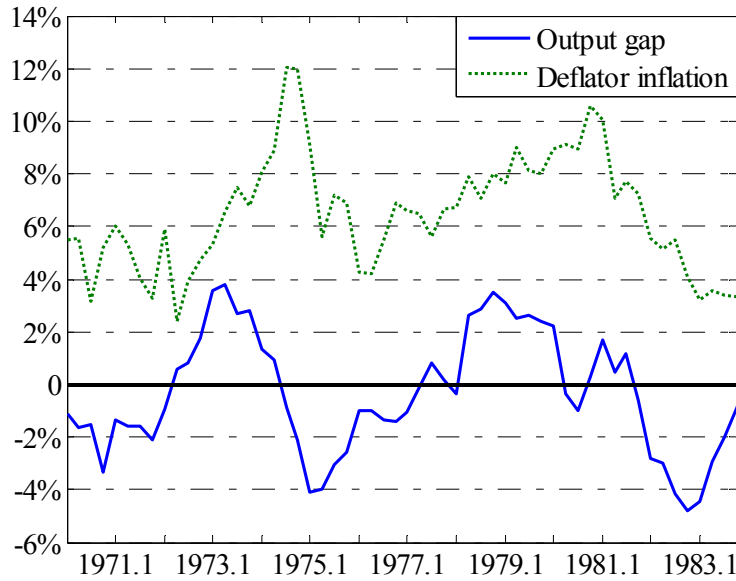
Notes: Inflation is annualized. The output gap is created via the HP filter. Real GDP is in billions of chained 1996 dollars. GDP deflator is chain-type price index with base year 1996. Both series are seasonally adjusted.

Figure 4: The U.S. Experience, 1959–2002
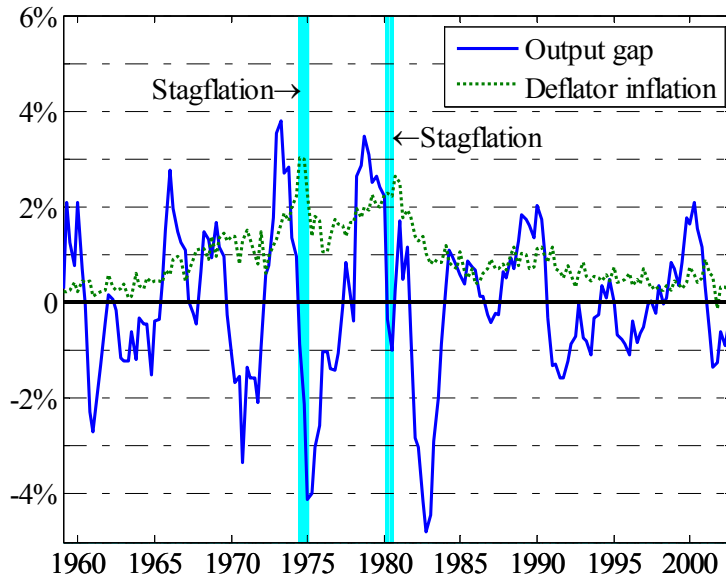
Notes: Stagflation is defined using the algorithm in the text. Inflation is not annualized. The output gap is created via the HP filter. Real GDP is in billions of chained 1996 dollars. GDP deflator is chain-type price index with base year 1996. Both series are seasonally adjusted.

Figure 5: Impulse Responses to a Transitory Shock to Money Growth, No Regime Changes Possible ($\beta = 0$)
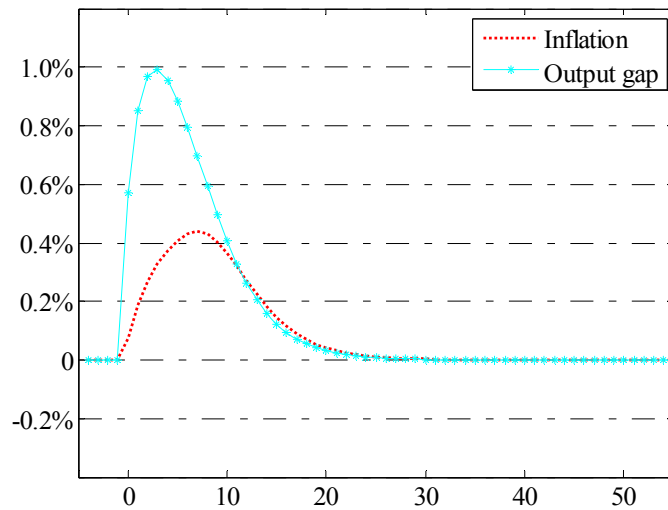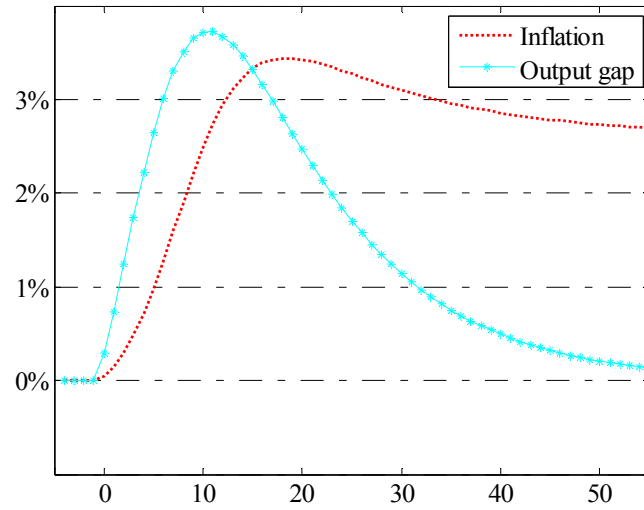

Notes: Response to a positive one standard deviation transitory shock to money growth. Inflation is annualized. Since $\beta=0$, firms know that the shock is transitory.

Figure 6: Impulse Responses to a Transitory Shock to Money Growth, Regime Changes Possible ($\beta > 0$)
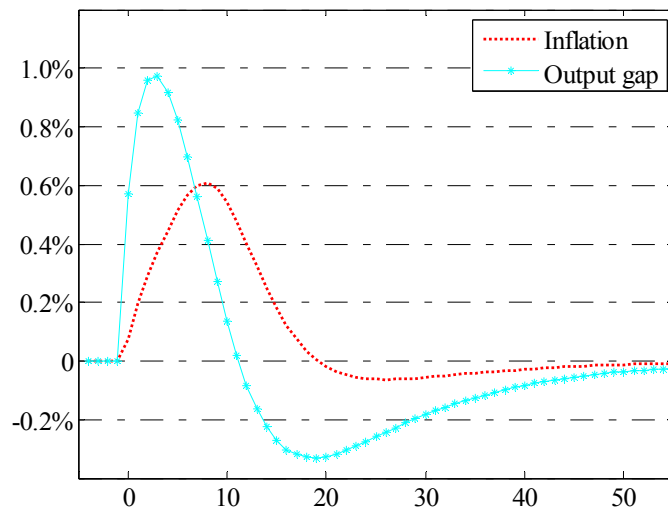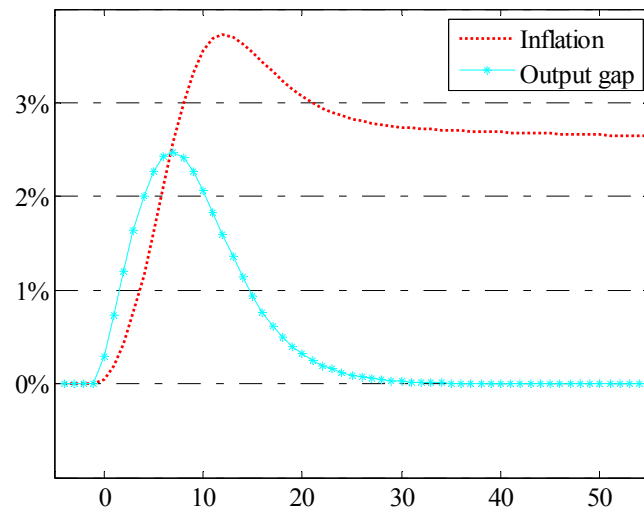

Notes: Response to a positive one standard deviation transitory shock to money growth. Inflation is annualized. Since $\beta>0$, firms must learn about the nature of the shock.

Figure 7: Impulse Responses to a Monetary Regime Change under Learning

Notes: Response to a positive one standard deviation monetary regime change. Inflation is annualized. Firms must learn about the nature of the shock.

Figure 8: Impulse Responses to a Monetary Regime Change, Transparent Central Bank

Notes: Response to a positive one standard deviation monetary regime change. Inflation is annualized. Firms know that the shock is a regime change.

Figure 9: Inflation Inertia and the Incidence of Stagflation
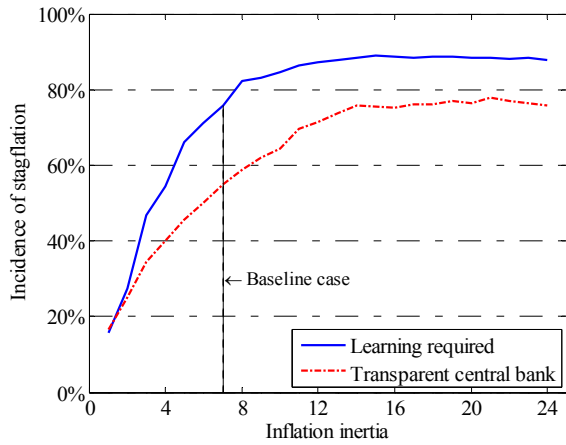
Figure 9(a): Sticky Information Model

Figure 9(b): Sticky Price Model
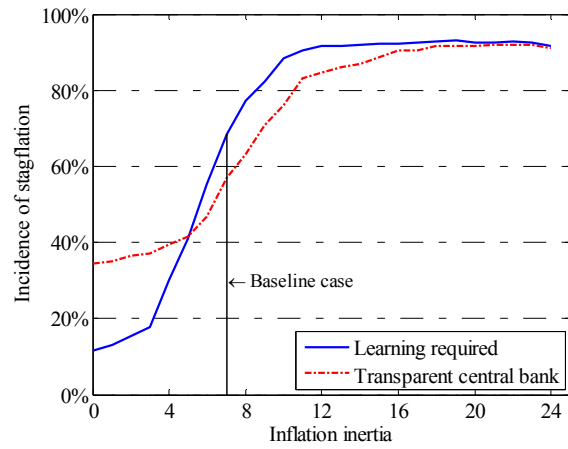
Notes: Inflation inertia is the number of quarters it takes for the inflation rate to peak in response to a known transitory shock to money growth. The real rigidity parameter (α) is varied in the sticky information model. The fraction of forward-looking firms (ω) is varied in the sticky price model. All other parameters are set as in the baseline case with β=0.025. See the text for details.

Table 1: Simulation Results and Stagflation

β	Implied average regime duration (in years)	Incidence of stagflation (% of simulations)	Average number of stagflationary quarters	Standard deviation of:		
				Money growth	Inflation	Output gap
0	–	5.8%	0.2	0.70%	0.31%	2.48%
0.005	50	42.1%	1.4	0.74%	0.43%	2.83%
0.01	25	60.5%	2.3	0.78%	0.52%	3.00%
0.025	10	75.9%	3.6	0.88%	0.70%	3.31%
0.05	5	84.4%	4.5	1.04%	0.93%	3.72%
0.1	2.5	86.5%	5.1	1.31%	1.29%	4.34%
0.25	1	90.0%	6.1	2.01%	2.10%	5.70%
		U.S. data:	5.0	0.88%	0.62%	1.55%

Notes: When β=0, no regime changes are possible and all firms know this. When β>0, firms use a signal-extraction problem to learn the nature of the monetary regime. Implied average regime duration is $1/\beta$ (converted into years). Incidence of stagflation is the percentage of simulations in which there is at least one stagflationary episode, as defined in Section II. Standard deviations for the simulated models are averages across the 1,000 simulations for the within-sample 176 quarter period. U.S. data are based upon the stagflation algorithm from Section II and the sample period 1959.1–2002.4.

Table 2: Separating Simulations into One Monetary Regime and Multiple Monetary Regimes

β	Implied average regime duration (in years)	One Regime		Multiple Regimes	
		Incidence of stagflation (% of simulations)	Average number of stagflationary quarters	Incidence of stagflation (% of simulations)	Average number of stagflationary quarters
0	–	5.8%	0.2	–	–
0.005	50	39.1%	1.0	44.3%	1.8
0.01	25	55.6%	1.5	61.2%	2.5
0.025	10	77.0%	2.5	75.9%	3.6
0.05	5	–	–	84.4%	4.5

Notes: When β=0, no regime changes are possible and all firms know this. When β>0, firms must use a signal-extraction problem to learn the nature of the monetary regime. Implied average regime duration is $1/\beta$ (converted into years). Simulations are separated ex post into the "One Regime" or "Multiple Regimes" groups depending upon whether the monetary regime changed during the simulation or not. Incidence of stagflation is the percentage of simulations in which there is at least one stagflationary episode, as defined in Section II.

Table 3: Central Bank Transparency and the Incidence of Stagflation

β	Implied average regime duration (in years)	Learning Required			Transparent Central Bank		
		All simulations	One regime	Multiple regimes	All simulations	One regime	Multiple regimes
0	–	–	–	–	5.8%	5.8%	–
0.005	50	42.1%	39.1%	44.3%	20.3%	5.8%	31.6%
0.01	25	60.5%	55.6%	61.2%	33.3%	5.8%	39.3%
0.025	10	75.9%	77.0%	75.9%	54.9%	5.8%	55.8%
0.05	5	84.4%	87.1%	84.4%	67.8%	5.8%	67.8%

Notes: Implied average regime duration is $1/\beta$ (converted into years). When $\beta=0$, no regime changes are possible and all firms know this. "Learning Required" implies that firms use a signal-extraction problem to learn the nature of the monetary regime when $\beta>0$. "Transparent Central Bank" implies that firms are able to see individual components of money growth with complete accuracy. Simulations are separated ex post into the "One Regime" or "Multiple Regimes" groups depending on whether the monetary regime changed during the simulation or not. Incidence of stagflation is the percentage of simulations in which there is at least one stagflationary episode, as defined in Section II. The same money growth process is used for the "learning required" and "transparent central bank" cases.

Table 4: The Incidence of Stagflation with a Hybrid New Keynesian Phillips Curve

β	Implied average regime duration (in years)	Learning Required			Transparent Central Bank		
		All simulations	One regime	Multiple regimes	All simulations	One regime	Multiple regimes
0	–	–	–	–	10.5%	10.5%	–
0.005	50	43.9%	39.5%	47.2%	25.6%	10.5%	34.9%
0.01	25	57.1%	49.3%	58.0%	36.0%	10.5%	41.4%
0.025	10	68.5%	58.4%	68.6%	56.9%	10.5%	57.7%
0.05	5	77.0%	62.7%	77.0%	67.3%	10.5%	67.3%

Notes: Implied average regime duration is $1/\beta$ (converted into years). When $\beta=0$, no regime changes are possible and all firms know this. "Learning Required" implies that firms use a signal-extraction problem to learn the nature of the monetary regime when $\beta>0$. "Transparent Central Bank" implies that firms are able to see individual components of money growth with complete accuracy. Simulations are separated ex post into the "One Regime" or "Multiple Regimes" groups depending on whether the monetary regime changed during the simulation or not. Incidence of stagflation is the percentage of simulations in which there is at least one stagflationary episode, as defined in Section II. The same money growth process is used for the "learning required" and "transparent central bank" cases, as well as for both the sticky price model (presented here) and the sticky information model (Table 3). See the text for details.