Sticky Information: A Model of Monetary Nonneutrality and Structural Slumps

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1. INTRODUCTION

How do employment and inflation respond to real and monetary forces? What frictions cause these macroeconomic variables to deviate from the ideals that would arise in a fully classical world? These questions are at the center of macroeconomic research, as well as at the center of much of Ned Phelps’s formidable research career. Early in his career Phelps (1967, 1968), together with Milton Friedman (1968), gave us the natural rate hypothesis, which remains the benchmark for understanding monetary nonneutrality. More recently, Phelps’s (1994) work on structural slumps examined the real forces that can cause the natural rate of unemployment to change over time.

This chapter offers a model that weaves these two threads of Phelps’s work together. In this model, information is assumed to disseminate slowly throughout the population of wage-setters, and as a result, wages respond slowly to news about changing economic conditions. Our model includes two kinds of relevant information: news about aggregate demand, as determined by monetary policy, and news about equilibrium real wages, as determined by productivity.

We introduce this sticky-information model in Section 2. The model generalizes the one in Mankiw and Reis (2001). In the earlier paper, we applied the assumption of sticky information to the price-setting process in order to understand the dynamic response of the economy to monetary policy. The resulting model has three properties that are consistent with the conventional wisdom of central bankers and the empirical evidence of macroeconomists. First, disinflations in the model are always contractionary (although announced disinflations are less contractionary than surprise ones). Second, the model predicts that monetary

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2. THE WAGE CURVE MEETS STICKY INFORMATION

The model we offer is designed to explain the dynamics of wages, prices, employment, and output. There are two key elements: the wage curve and the assumption of sticky information.

2.1. The Wage Curve

The starting point is an equation describing the target nominal wage \( w^* \):

\[ w^* = p + \theta \epsilon + \alpha \epsilon, \]

where \( p \) is the price level, \( \theta \) is labor productivity, and \( \epsilon \) is employment. All the variables are in logs, and employment is normalized so that it averages zero. This equation resembles the wage curve, as in Phelps (1994) and Blanchflower and Oswald (1995). Some might call it a "pseudo labor supply curve."

The simplest way to motivate this equation is from the standpoint of a union that sets wages. The union has a target for the real wage that depends on its workers’ productivity. In addition, high employment makes the union more aggressive, raising the wages they demand.

Another way to view this wage equation is from the standpoint of a firm that sets wages in an efficiency-wage environment. The wage curve describes a "no-shirking condition." Firms pay productive workers more because they have better outside alternatives. In addition, high employment increases shirking among workers because unemployment is less of a threat. As a result, high employment induces firms to offer higher wages.

2.2. The Sticky Information Assumption

To this standard wage curve, we add the assumption that wage-setters make their decisions based on imperfect information. Every wage-setter sets a new wage every period, but they collect information about the economy and update their decisions slowly over time.

Our assumption about information arrival is analogous to the adjustment assumption in the Calvo (1983) model of price adjustment. That is, adjustment occurs as a Poisson process. In each period, a fraction \( \lambda \) of the wage-setters obtains new information about the state of the economy and recomputes optimal plans based on that new information. Other wage-setters continue to set wages based on old plans and outdated information. Each wage-setter compiles new information, regardless of how long it has been since its last update.¹

¹ A natural question is whose expectations suffer from the stickiness of information. Under the union interpretation of the wage curve, the expectations are clearly those of the union workers. The answer is less obvious in the efficiency-wage interpretation, according to which the wage curve represents the no-shirking condition. In this case, firms set the wages, but because the firms are trying to induce workers not to shirk, the expectations of the workers are again relevant.

2.3. The Sticky-Information Phillips Curve

We can solve for the price level as a function of output by combining the previous five equations. The resulting aggregate supply equation is

\[ p_t = \left( \lambda \sum_{j=0}^{\infty} (1 - \lambda)^j E_{t-j} \left[ p_t + \alpha \epsilon_t + (1 - \alpha) \frac{\epsilon_t}{\theta} \right] \right) - \theta. \]

With this equation in hand, another special case is apparent. If there are no productivity shocks (\( \theta = 0 \)), the model simplifies to the price adjustment model in Mankiw and Reis (2001). Thus, the results in that paper concerning the dynamic effects of aggregate demand apply here as well.

With some tedious algebra, which we leave to the appendix, this equation for the price level yields the following equation for the inflation rate:

A wage-setter that last updated its information \( j \) periods ago sets the wage

\[ w_t^j = E_t \cdot w_t^0. \]

The aggregate wage is the average of wages in the economy:

\[ w_t = \lambda \sum_{j=0}^{\infty} (1 - \lambda)^j w_t^j. \]

These two equations, together with the wage-curve equation above, fully describe the process of wage setting.

The rest of the model is conventional. The overall price level is determined by the level of wages and labor productivity:

\[ p_t = w_t - \theta. \]

This equation is both the supply curve in the output market (prices depend on costs) and the demand curve in the labor market (the real wage depends on productivity). The level of output is determined by employment and labor productivity:

\[ y_t = \epsilon_t + \theta, \]

This is the production function. The above five equations together make up the aggregate-supply side of the model.

It is worth noting what happens in the limiting case when information is perfect (\( \lambda = 1 \)). It is straightforward to show that in this case, \( \epsilon = 0 \) and \( y = \theta. \) That is, under perfect information, employment is constant and output mirrors productivity. In this model, all employment dynamics follow from the assumed stickiness of information.
\[ p_t = [a(1 - \lambda)]e_t - \Delta b_t + \sum_{j=0}^{\infty} (1 - \lambda)^j E_{t-j} / (\rho + \Delta b_t + \sigma \Delta e_t), \]

where \( \Delta e_t = e_t - e_{t-1} \). We call this the sticky-information Phillips curve.

Let us examine each of the determinants of inflation in this model: (1) High employment means higher inflation: This is the conventional short-run Phillips curve. Here it arises because high employment raises target wages, which in turn raises costs and thus the prices charged by firms. (2) Higher productivity growth lowers inflation because it lowers firms' costs of production. (3) Higher expected inflation raises inflation because, by virtue of the sticky-information assumption, past expectations are still affecting current wage increases. (4) Higher expected productivity growth raises inflation because it influences the wages that wage-setters thought were appropriate. (5) Higher expected employment growth also raises inflation because it also influences expected target wages.

2.4. Comparison to a Leading Competitor

This sticky-information Phillips curve is very different from the "new Keynesian Phillips curve," which has become popular in recent years. The latter model, based on the work of Taylor (1980), Rotemberg (1982), and Calvo (1983), implies an expectation-augmented Phillips curve, where current inflation depends on the expectation of next period's inflation. Ignoring productivity shocks for the moment, we can write the new Keynesian Phillips curve as

\[ p_t = \pi e_t + E_{t} \pi_{t+1}. \]

For a notable example of a paper applying this model of inflation dynamics, see Clarida et al. (1999). McCallum (1997) has called this model "the closest thing there is to a standard specification," while Goodfriend and King (1997) said that it is part of a "new neoclassical synthesis" in macroeconomics.

Yet this model has some significant empirical flaws. Mankiw (2001) argues that it is inconsistent with conventional views about the effects of monetary policy. Mankiw and Reis (2001) compare it with a simple version of the sticky-information model and show that the latter yields more plausible dynamics. In particular, according to the new Keynesian Phillips curve, inflation responds immediately and substantially to monetary shocks, whereas according to the sticky-information Phillips curve, the effect of monetary shocks on inflation is delayed and gradual.

The key difference between the models comes from the role of expectations. The new Keynesian Phillips curve gives a prominent role to current expectations of future inflation. These expectations can adjust quickly in response to changes in monetary policy. By contrast, the sticky-information Phillips curve gives a prominent role to past expectations of current inflation. These expectations are predetermined and thus cannot change quickly. In this way, the sticky-information model more closely resembles an earlier generation of price-adjustment models proposed by Fischer (1977) and Phelps and Taylor (1977).
The two inflation paths in the bottom panel of Figure 1 are quite different from each other. In the case of a slowdown in money growth, inflation declines only gradually. It overshoots the new lower level briefly as agents learn of the new regime and correct their previous mistakes. In the case of a productivity slowdown, inflation immediately spikes up, as firms pass on higher costs to consumers. Inflation gradually declines as wages start reflecting lower productivity growth. After a brief period of overshooting, inflation eventually settles at a new higher level.

The reader might have noticed that the dynamic paths for employment are similar in the case of disinflations and productivity slowdowns. This is not a coincidence. In fact, the appendix proves the following:

**Proposition:** Productivity has an impact on employment that is exactly $1 - \beta$ times that of aggregate demand.

This naturally leads to:

**Corollary:** If the aggregate demand curve is unit elastic ($\beta = 1$), then productivity has no effect on employment.

The intuition behind the corollary is the following: Adverse news about productivity influences target nominal wages in two ways. They fall because target real wages are lower, and they rise because the price level is higher. If $\beta = 1$ and the path of $m$ is held constant, these two effects exactly cancel. In this special case, wages stay exactly on track to maintain full employment, despite the slow diffusion of information.

4. STABILIZATION POLICY IN THE FACE OF PRODUCTIVITY CHANGE

The outcomes shown in Figure 1 assume that when the economy experiences a productivity slowdown, the monetary authority holds aggregate demand on the same path that it otherwise would have followed. This benchmark is natural, but it need not hold. As employment and inflation fluctuate, the monetary authority may well respond by altering aggregate demand. Here we consider two other natural benchmarks.

One possibility is that the monetary authority may choose a policy to stabilize employment. This means it would adjust aggregate demand $m$ to keep $e = 0$ at all times. Because fluctuations in employment in this model arise because of imperfections in private information and because the monetary authority is assumed to have full information, it might well try to achieve the level of employment and output that private decision-makers would choose on their own if only they were better informed.

Alternatively, the central bank may choose to stabilize inflation. This means it would adjust aggregate demand to maintain a constant inflation rate. This benchmark is interesting in part because many central banks are in fact now committed to inflation targeting as a policy framework (although many such regimes allow temporary deviations from a strict target).
There is also another reason to focus on the employment path that follows under an inflation-stabilizing policy: This path corresponds to what economists might measure as the NAIRU (the nonaccelerating inflation rate of unemployment). In this model, the natural rate of employment—that is, the level that would prevail with full information—is assumed constant. Yet the rate of employment associated with nonaccelerating inflation is not constant. To find the level of employment that corresponds to the measured NAIRU, we can solve the model assuming that monetary policy stabilizes inflation.

Figure 2 shows employment and inflation in response to a productivity slowdown under three policies: constant aggregate demand, employment stabilization, and inflation stabilization. The appendix presents the details of solution.

The figure shows that inflation stabilization leads to very large fluctuations in employment. To extinguish the impact on inflation, monetary policy responds to the adverse shift in aggregate supply by contracting aggregate demand. This instability in employment under inflation stabilization can be viewed as a warning to the many central banks around the world that have adopted inflation targeting. In essence, a productivity slowdown in this model looks like a rise in the NAIRU, which is consistent with the empirical results in Ball and Mofifit (2001) and Staiger et al. (2001). Yet the natural rate—the level of employment that would prevail under full information—has not changed. The fall in employment that results from a productivity slowdown is no more desirable in this model than any other downturn.

A policy of inflation stabilization not only tolerates the downturn in employment but exacerbates it to keep inflation under control.

Figure 2 also shows that a policy of employment stabilization leads to a permanent rise in the inflation rate. That is, for the central bank to maintain full employment during a productivity slowdown, it has to accommodate the adverse shift in aggregate supply by raising aggregate demand, permitting a higher inflation rate. The rise in inflation needed to stabilize employment equals the magnitude of the slowdown in productivity growth. That is, a slowdown of 2 percent per year requires an increase in the inflation rate of 2 percentage points.

There are other ways to describe the policy of stabilizing employment. It turns out that along the path with stable employment, both nominal income $p = \gamma$ and the nominal wage $w$ equal their previously expected values. Turning this observation around leads to a policy: If the central bank commits to keeping either nominal income or the nominal wage at a constant level (or growing at some constant rate), aggregate demand and inflation in the price of goods and services will automatically respond to a productivity shift by exactly the right amount to maintain full employment.

Overall, this model suggests that inflation targeting may not be the best framework for monetary policy in the face of changing productivity. A better target variable than the price of goods and services is nominal income or the price of labor. Like inflation targeting, targeting nominal income or the nominal wage gives monetary policy a nominal anchor, but it does so in a way that permits greater stability in employment. There is a long tradition suggesting the desirability of nominal income targeting; see Tobin (1980) and Hall and Mankiw (1994) for two examples. But, as far as we know, the possibility of targeting the price of labor has not received much attention.

One exception is the plan discussed by Phelps (1978). He concludes, "the program envisioned here aims to stabilize wages on a level or rising path, leaving the price level to be buffeted by supply shocks and exchange rate disturbances."
This is precisely the policy suggested by the sticky-information model of wage setting. We agree with Phelps that nominal wage targeting seems like a promising alternative to inflation targeting as a monetary policy rule.1

5. AN EMPIRICAL APPLICATION

In the model presented here, inflation and productivity surprises drive employment fluctuations. This section examines this prediction using U.S. time-series data to get a sense of how well the model works and to learn where it has problems matching the world.

5.1. The Approach

We start with the sticky-information Phillips curve presented earlier:

\[ \pi_t = [\alpha (1 - \lambda)] \varepsilon_t - \Delta \theta + \lambda \sum_{j=0}^{\infty} (1 - \lambda)^j E_{t-\lambda-j} (\pi_{t+j} + \Delta \theta + \alpha \Delta \varepsilon_{t+j}) \]

Now we turn this equation around to use it as a theory of employment:

\[ \varepsilon_t = \frac{1}{(1 - \lambda) / \alpha} \left[ \pi_t + \Delta \theta - \lambda \sum_{j=0}^{\infty} (1 - \lambda)^j E_{t-\lambda-j} (\pi_{t+j} + \Delta \theta + \alpha \Delta \varepsilon_{t+j}) \right] \]

which implicitly expresses employment as a function of inflation, productivity, and the past expectations of these variables. Our goal is to see whether this equation can help explain observed U.S. fluctuations. To do this, we make two auxiliary assumptions.

First, we assume that inflation and productivity growth follow univariate stochastic processes. Their moving average representations can be written as

\[ \pi_t = \sum_{j=0}^{\infty} \psi_j \pi_{t-j} \quad \text{and} \quad \Delta \theta_t = \sum_{j=0}^{\infty} \eta_j \lambda_{t-j}. \]

In this case, the expectations of inflation and productivity growth are a function of their past univariate innovations.2 As the appendix shows, the model can now be solved as

\[ \varepsilon_t = \sum_{j=0}^{\infty} \psi_j \varepsilon_{t-j} + \sum_{j=0}^{\infty} \eta_j \varepsilon_{t-j}, \]

where the parameters \( \psi_j \) and \( \eta_j \) are functions of \( \beta, \eta, \lambda \), and \( \lambda \). This equation can be used to predict fluctuations in employment, taking as inputs the univariate innovations in inflation and productivity.

Second, we assume that the observed unemployment rate is linearly related to a moving average of \( \varepsilon \), the employment variable in our model. In particular, the unemployment rate \( u \) is assumed to be

\[ u_t = \delta_0 - \delta_1 \varepsilon_t, \]

where \( \varepsilon_t \) is defined as

\[ \varepsilon_t = (\varepsilon_{t-1} + 2 \varepsilon_{t-2} + 3 \varepsilon_{t-3} + 4 \varepsilon_{t-4} + 3 \varepsilon_{t-5} + 2 \varepsilon_{t-6} + \varepsilon_{t-7}) / 16. \]

We found that without any smoothing of the predicted employment variable, the model produces too much high-frequency variation in the predicted unemployment rate. This triangular filter smooths out the rapid quarter-to-quarter fluctuations in the predicted series, leaving the business cycle variation and the longer-term trend.3

Given these two auxiliary assumptions, we can use the model to produce a predicted path of unemployment for any given set of parameters. The predicted unemployment rate in any period depends on the history of shocks to inflation and productivity.

5.2. Parameter Estimation

The next issue is how to choose the parameters. We estimate the parameters of the univariate processes for inflation and productivity growth as autoregressions using ordinary least squares. We then invert these autoregressions to obtain \( \rho \) and \( \eta \), the parameters of the moving average representations. The residuals from the autoregressions are the shocks \( \varepsilon \) and \( \lambda_t \), which we feed into the model to explain fluctuations in unemployment.

The remaining three parameters are \( \lambda, \delta_0 \), and \( \delta_1 / \alpha \). (The parameters \( \alpha \) and \( \delta_1 \) are not identified separately.) We estimate these parameters using a least-squares procedure; that is, we choose these parameters to minimize the sum of squared deviations between predicted and actual unemployment.

The results from this procedure have a simple interpretation. The estimated \( \delta_0 \) equals the mean unemployment rate. The estimated \( \delta_1 / \alpha \) ensures that the prediction

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1. Artis (2001) presents a related result: In a world with a sticky-price sector and a flexible-price sector, optimal monetary policy targets inflation in the sticky-price sector. In our model, the labor market is analogous to the sticky-price sector.

2. In reality, expectations may also depend on other information. For example, news about monetary policy may affect expected inflation. But experience suggests that the improvement from multivariate over univariate forecasting is often slight. Future work could improve upon this assumption, but we probably do not go too far wrong in assuming univariate processes for inflation and productivity growth.

3. There are two natural hypotheses to explain the high-frequency variation predicted by the model without the filter. (1) Some high-frequency variation in productivity growth and inflation is measurement error. (2) The high-frequency variation in productivity growth and inflation in the data is real, but for some reason, employment responds these sluggishly in the world than it does in our model. Very possibly each explanation has an element of truth.
error is not correlated with the predicted value. These two parameters do not affect the autocorrelations of predicted unemployment or the cross-correlations between predicted and actual. In some sense, these parameters are not interesting. Changing $\lambda$, and $\lambda$ alters the mean and variance of predicted unemployment without altering the dynamics in any other way. The interesting parameter is $\lambda$, which measures the rate of information arrival. One least-squares procedure picks this parameter to make the model fit the data. In particular, it picks the value for $\lambda$ that maximizes the correlation between predicted and actual unemployment.

5.3. Data and Results

We use quarterly, seasonally adjusted U.S. data from the first quarter of 1959 to the first quarter of 2001. Inflation is measured by the consumer price index. Productivity growth is the growth of output per hour in the business sector. Unemployment is the civilian unemployment rate. The univariate autoregressions indicate that inflation and productivity growth follow very different stochastic processes. Productivity growth is indistinguishable from white noise, indicating no persistence. By contrast, inflation is well modeled as an AR(3) with autoregressive parameters 0.37, 0.22, and 0.29. These three coefficients on lagged inflation sum to 0.88, indicating that inflation is borderline nonstationary. We use the white noise specification for productivity growth and the AR(3) parameters for inflation to calculate the moving average parameters and the estimated innovations.

Next we fit the model using the unemployment data. The estimated value of $\lambda$, the rate of information arrival, is 0.25. This means that wage setters in the economy update their information on average every four quarters. Figure 3 shows the actual and predicted unemployment rate using this estimate. The correlation between these two series is 0.47.

Figure 4 decomposes the predicted unemployment rate from Figure 3 into two pieces. The top panel shows the piece of predicted unemployment that is driven by inflation innovations. The bottom panel shows the piece of predicted unemployment that is driven by productivity innovations. Actual unemployment is shown in both panels, and all the parameters are held constant at the same values as in Figure 3.

The figure shows that inflation and productivity innovations are both important for explaining unemployment. The correlation of unemployment with the inflation piece of the predicted series is 0.33. The correlation of unemployment with the productivity piece is 0.17.

Inspection of Figure 4 reveals an anomaly: Unemployment as predicted by productivity innovations moves in advance of actual unemployment. Although this piece of predicted unemployment has a correlation with contemporaneous unemployment of only 0.17, its correlation with unemployment 1 year ahead is 0.48. Productivity appears to take more time to influence unemployment in the world than it does in our model.

As a rough (and, we admit, ad hoc) fix for this lagged response, we add a four-quarter delay to the estimated model. The employment equation then becomes

$$\Delta y_t = \sum_{j=0}^{\infty} \Psi_j \epsilon_{t-j} + \sum_{j=0}^{\infty} \Psi_j \mu_{t-j-4}.$$

Otherwise, the model and estimation procedure are the same. The estimate of $\lambda$ is now 0.26, almost identical to our earlier estimate. The predicted and actual unemployment rates, shown in Figure 5, now have a correlation of 0.60. Adding this lag in the effect of productivity significantly improves the model's fit.

In the end, the empirical verdict on this model is mixed. On the one hand, the model fails to capture some important dynamics in the data. The delay between productivity innovations and unemployment is a puzzle. On the other hand, 6. This delay in the response to productivity shocks may be related to the mechanism highlighted in Baa et al. (1998). If prices are sticky in the slow way, then a good productivity shock can reduce
inflation and productivity surprises can account for much of the observed evolution in U.S. unemployment. The simulation in Figure 5 captures many of the main features of the unemployment data, including the big recessions in 1975 and 1982, the rising trend level of unemployment rate during the 1970s and early 1980s, and the declining unemployment rate in the late 1990s.

There are many ways in which this empirical model could be improved. The model excludes many determinants of unemployment, such as changing demographics, unionization, and minimum wage laws. It also excludes many shocks that might shift the inflation-unemployment relationship, such as exchange rates, food and energy prices, and wage-price controls. The only inputs into these simulations are inflation and productivity surprises. Absent changes in measured productivity, the model interprets all movements in inflation as driven by aggregate demand. Incorporating other sources of inflation and inflation fluctuations into the model and adding a richer dynamic structure to better explain the link between productivity and employment are tasks we leave for future work.

6. CONCLUSION

Since Friedman (1968) and Phelps (1967, 1968) introduced the natural rate hypothesis in the 1960s, expectations have played a central role in understanding the dynamics of inflation and employment. Early empirical work testing the hypothesis was based on the assumption of adaptive expectations, according to which expected inflation is a weighted average of past inflation. Yet Lucas (1972) and Sargent (1971) forcefully criticized that approach. Since then, economists have most often relied on the assumption of rational expectations.

Over time, however, economists have increasingly realized that while agents may be too smart to form expectations adaptively, they may not be smart enough to form them rationally. Unfortunately, finding a safe haven between the stupidity of adaptive expectations and the hyperintelligence of rational expectations is
not easy. Friedman (1979), Summers (1986), and Sargent (1999) have explored the possibility that least-squares learning can help explain how expectations evolve over time. Sims (2001) has suggested modeling agents’ limited capacity for processing information. Ball (2000) has proposed that agents form optimal univariate forecasts, but ignore the possible gains from multivariate forecasts. Each of these approaches has some appeal, but each lacks the parsimony that makes rational expectations so compelling.

Like all these efforts, the sticky-information model we have explored here and in our previous paper attempts to model agents that are smart, but not too smart. Our agents form expectations rationally, but they do not do so often. Because of either costs of acquiring information or costs of recomputing optimal plans, information diffuses slowly throughout the population. As a result, expectations conditional on old information continue to influence current behavior.

Recently, many economists have been pursuing “behavioral economics,” a research program that tries to incorporate the insights of psychology into economics. The starting point of this work is the observation that people are not quite as rational as the homo economicus assumed in standard models. The sticky-information model of inflation-unemployment dynamics can be viewed as a modest contribution to this literature. The closest antecedent is the work of Gabaix and Laibson (2001), which tries to explain consumption behavior and the equity premium puzzle by assuming that consumers are slow to recognize changes in the values of their portfolios. The sticky-information model we have presented here applies the analogous assumption to the process of wage setting.

From a theoretical standpoint, assuming sticky information is an attempt to have your cake and eat it too. Like many previous efforts, our model tries to describe agents who do not fully understand their environment and gradually learn about it over time. This lack of full understanding motivates our application of Calvo’s assumption of Poisson adjustment to the acquisition of information. Whether this approach is the best way to model the imperfections of human behavior is hard to say. But without doubt, it has a major advantage: Once this leap of faith is taken, the powerful tools of rational expectations become available to solve for the resulting equilibrium.

Of course, the validity of this model of inflation-unemployment dynamics is ultimately an empirical question. The model fits some broad stylized facts. In our previous paper, we showed that the model can explain the dynamic response of the economy to monetary policy. It can explain why disinflations are costly, why monetary shocks have a delayed and gradual effect on inflation, and why changes in inflation are positively correlated with the level of economic activity. This chapter has moved the analysis to the labor market and introduced a role for productivity as a driving force. The model can now explain why productivity slowdowns, such as the one that occurred in the 1970s, are associated with rising unemployment (and a rising NAIRU) and why productivity accelerations, such as the one that occurred in the United States in the 1990s, are associated with declining unemployment (and a declining NAIRU). When we applied the model to U.S. time-series data, we found that inflation and productivity surprises account for a sizable fraction of observed unemployment fluctuations.

STICKY INFORMATION

The model proposed here suggests a possible problem with the policy of inflation targeting that many of the world's central banks adopted during the 1990s. In this model, stabilizing employment in the face of a productivity slowdown requires a rise in the inflation rate of an equal magnitude. The model suggests that a better nominal anchor than the price of goods and services is nominal income or the nominal wage. Targeting inflation in the price of labor, rather than in the price of goods and services, is a policy rule that deserves a closer look.

APPENDIX

This appendix formally justifies some of the claims asserted in the body of the chapter.

The Sticky-Information Phillips Curve

The three equations describing wage setting, together with the demand for labor, lead to

\[ p_t = \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}(p_t + \sigma \epsilon_t + \theta_t) - \theta_t. \]  

(A1)

Take out the first term to obtain

\[ p_t = \lambda (p_t + \sigma \epsilon_t + \theta_t) + \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}(p_t + \sigma \epsilon_t + \theta_t) - \theta_t. \] 

(A2)

and subtract the \( p_{t-1} \) version of (A1) from (A2) to obtain, after some rearranging,

\[ \pi_t = \lambda (p_t + \sigma \epsilon_t + \theta_t) + \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}(\pi_t + \sigma \Delta \epsilon_t + \Delta \theta_t) - \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}(p_t + \sigma \epsilon_t + \theta_t) - \Delta \theta_t. \] 

(A3)

where \( \Delta \) is the first difference operator and the inflation rate is \( \pi_t = \Delta \theta_t. \)

Multiplying through equation (A2) by \( \lambda \) and rearranging, we get

\[ (1-\lambda) \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}(p_t + \sigma \epsilon_t + \theta_t) = \lambda (1-\lambda) p_t + \lambda \sigma \epsilon_t + (1-\lambda) \theta_t. \] 

(A4)

Replacing (A4) for the last term in (A3) leads to, after rearranging, the sticky-information Phillips curve:
\[ \pi_t = \frac{\alpha_t}{(1-\lambda)}\varepsilon_t - \Delta h_t + \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}(\pi_t + \Delta h_t + \alpha \Delta e_t). \quad (A5) \]

The Response of Employment and Inflation to a Fall in the Growth Rate of Aggregate Demand and Productivity

Replacing \( v \) using the aggregate demand equation into the aggregate supply equation, we obtain the law of motion for the price level:

\[ p_t = \left( \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}\left[1-\alpha/\beta \right] p_{t+j} + (\alpha/\beta) m_t, + (1-\alpha/\beta) \theta_t \right) - \theta_t. \quad (A6) \]

First, say that \( m_t \) was growing at the rate 0.005, up to date \(-1\), when it reaches the level 0. Then, unexpectedly, the growth rate falls to 0, so \( m_t \) stays at level 0 forever. Formally: \( m_t = 0.005(1+r) \) for \( t \leq -1 \) and \( m_t = 0 \) for \( t \geq 0 \). Also, set \( \theta_t = 0 \) for all \( t \). Then, we can break equation (A6) into two components:

\[ p_t = \frac{\lambda}{\beta} \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}\left[1-\alpha/\beta \right] p_{t+j} + (\alpha/\beta) m_t, + (1-\alpha/\beta) \theta_t \]
\[ + \lambda \sum_{j=t+1}^{\infty} (1-\lambda)^j E_{t-j}\left[1-\alpha/\beta \right] p_{t+j} + (\alpha/\beta) m_t, \]

or

\[ p_t = (1-\alpha/\beta) \left[ 1 - (1-\lambda)^{t+1} \right] \theta_t + 0.005(1+r)(1-\lambda)^{t+1}. \quad (A7) \]

In the first summation term are included the agents that set their expectations after the change in \( m_t \). Thus, they set expectations with full information: \( E_{t-j}(p_t) = p_t \) and \( E_{t-j}(m_t) = 0 \). In the second summation term are agents who set expectations prior to the change: \( E_{t-j}(p_t) = E_{t-j}(m_t) = 0.005(1+r) \). Thus, (A7) becomes

\[ p_t = \frac{0.005(1+r)(1-\lambda)^{t+1}}{1 - (1-\alpha/\beta) \left[ 1 - (1-\lambda)^{t+1} \right]} \quad (A9) \]

Employment is given by \( e_t = -p_t/\beta \) and inflation is \( \pi_t = \Delta p_t \).

The fall in productivity is formalized as: \( \theta_t = 0.005(1+r) \) for \( t \leq -1 \) and \( \theta_t = 0 \) for \( t \geq 0 \), and \( m_t = 0 \) for all \( t \). Starting again from (A6) we obtain, by very similar steps, the response of prices:

\[ p_t = \frac{0.005(1-\beta)(1+r)(1-\lambda)^{t+1}}{1 - (1-\alpha/\beta) \left[ 1 - (1-\lambda)^{t+1} \right]} \quad (A10) \]

Inflation and employment follow immediately.

STICKY INFORMATION

Proof of the Proposition and Corollary

Starting from (A1), replacing \( p_t \) from the aggregate demand equation and for \( \gamma_t \) from the production function, we obtain the expectational difference equation for employment as a function of the two exogenous processes, \( m_t \) and \( \theta_t \):

\[ \beta e_t = m_t + (1-\beta)\theta_t - \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}[m_{t+j} + (1-\beta)\theta_{t+j} + (\alpha - \beta)\varepsilon_{t+j}]. \quad (A11) \]

If we define the composite disturbance as \( m_t + (1-\beta)\theta_t \), employment is driven solely by this term. Shocks to \( m_t \) or \( (1-\beta)\theta_t \) have exactly the same effect on the equation above and thus on employment. This shows the proposition. The corollary follows from setting \( \beta = 1 \) in (A11) and noting that \( \theta_t \) does not enter the stochastic equation determining employment.

Stabilization Policy and Productivity Change

We start with the stable employment policy. From (A11), it follows that if \( m_t = -\lambda \theta_t \), then we obtain an expectational difference equation involving only \( e_t \), which has solution \( e_t = 0 \). This is the policy that stabilizes employment. Given the path for \( \theta_t \) above, we have the policy path \( m_t \), and since we know that this ensures \( e_t = 0 \), then \( \gamma_t = \theta_t \), from the production function. The path of prices \( p_t \) comes from the aggregate demand equation \( p_t = \theta_t \). A permanent drop in the growth rate of productivity therefore leads to a permanent rise in inflation.

Alternatively, note that combining the wage curve and the labor demand (output supply) equations into the equation for the aggregate wage we obtain

\[ w_t = \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}[w_{t+j} + \alpha e_{t+j}]. \quad (A12) \]

From (A12), having the wage rate equal to some forever known constant ensures that \( e_t = 0 \). Without loss of generality, we set that constant to zero. The associated policy is \( m_t = -(1-\beta)\theta_t \), from using the aggregate demand equation and the production function. Thus, an employment stabilization policy is equivalent to a policy that stabilizes the wage rate in the sense of having \( w_t \) deterministic or known to all.

Similarly, we use the labor demand and the production function equations to replace \( w_t \) and \( \theta_t \) in (A12) above and obtain

\[ p_t + \gamma_t - \theta_t = \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j}[p_{t+j} + \gamma_{t+j} + (1-\alpha)\varepsilon_{t+j}]. \quad (A13) \]

Thus, by the same argument as above, stabilizing nominal income \( p_t + \gamma_t \) is equivalent to stabilizing employment.
We now turn our attention to inflation targeting. Without loss of generality we set the target to zero, and the level to zero as well, so the policy aim is to have $p_t = 0$ at all periods. From the law of motion for the price level in (A6) and the set path for prices:

$$\theta_t = \lambda \sum_{i=0}^{\infty} (1 - \lambda)^i \epsilon_{t-i} (a/\beta)m_i + (1 - a)\theta_i. \tag{A14}$$

Given a path for $\theta_t$, the necessary path of policy is given by the solution to this equation. For $t < -1$, all agents have full information and $\theta_t = 0.005(1 + \epsilon_t)$ so the policy is $m_t = 0.0055(1 + \epsilon_t)$. For $t \geq 0$, breaking the sum in two components, the first referring to informed agents that set their expectations at or after date 0 and the second to uninformd agents that set their expectations before date 0, we obtain

$$0 = (a/\beta)[1 - (1 - \lambda)^{y'}]m_t + 0.005(1 + \epsilon_t)(1 - \lambda)^{y'}. \tag{A15}$$

which, after rearranging, becomes

$$m_t = \frac{-0.0055\beta(1 + \epsilon_t)(1 - \lambda)^{y'}}{a - a(1 - \lambda)^{y'}}. \tag{A16}$$

The path for employment for $t \geq 0$ is $e_t = y_t = m_t/\beta$.

**Empirical Implementation**

Since the only forces driving employment are inflation and productivity growth, the general solution for employment will be a linear function (with undetermined coefficients) of the shocks to these variables:

$$ae_t = \sum_{i=0}^{\infty} (y_{t+i} + \Psi_{t+i}). \tag{A17}$$

Using the MA representations for inflation, productivity growth, and employment; plugging these into the equation for employment in the main text; and taking the relevant expectations, we obtain

$$\sum_{i=0}^{\infty} (y_{t+i} + \Psi_{t+i}) = \frac{1 - \lambda}{\lambda} \left( \sum_{i=0}^{\infty} (\rho_{t+i} + \eta_{t+i}) \right) \tag{A18}$$

Finally, the decomposition of predicted unemployment in Figure 4 follows directly from the two components of (A17).

**REFERENCES**


A Theory of Rational Inflationary Inertia

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If there is such a thing as an economy with a rock-solid inflation rate of 40 per cent, plus or minus 2 per cent, per year, institutions would surely adapt, so that prices would be announced in catalogs and wage contracts with smooth growth paths parallelizing the smooth aggregate price path. Nominal rigidity would set in about this price path in much the same form as we see around the zero inflation rate in low-inflation economies. (Sims, 1988, p. 77)

1. INTRODUCTION

Monetary theory today is dominated by fully microfounded dynamic general equilibrium models incorporating, in one form or another, the assumption of sticky prices. A comprehensive survey of this literature is contained in Clarida et al. (1999) for closed economies and Lane (2001) for open economies. The renewed popularity of sticky-price monetary economics was motivated by empirical findings that demonstrated, at least for the U.S. case, that monetary policy has significant real effects, contrary to the premise of the real business cycle literature. Examples of that empirical literature include Christiano et al. (1996, 1998) and Leeper et al. (1996). As surveyed in Taylor (1998), the assumption of sticky prices does a good job in explaining most, but not all, features of those data. That paper also documents the micro- and macroeconomic evidence supporting the sticky-price assumption itself.

The 1990s resurgence of this model class would have been hard to predict from a 1970s vantage point. At that time, in the wake of the rational expectations revolution, the sticky-price assumption was closely associated with old-style Keynesian models featuring adaptive expectations, and many economists discarded these two concepts together. But at that same time a group of researchers started to build the theoretical foundations for the incorporation of sticky prices into rational expectations models, and it is to their work that the new generation of models...