Pervasive Stickiness

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This paper explores a macroeconomic model of the business cycle in which stickiness of information is a pervasive feature. Prices, wages, and consumption are all assumed to be set, to some degree, based on outdated information sets. We show that a model with such pervasive stickiness is better at matching some key facts describing economic fluctuations than is either a benchmark classical model without such informational frictions or a model with only a subset of these frictions.

The benchmark classical model that provides the starting point for this exercise will seem familiar. Prices are based on marginal cost; wages are based on the marginal rate of substitution between work and leisure; the demand for output is derived from a forward-looking consumption Euler equation; and interest rates are set by the central bank according to a conventional Taylor rule. The economy is buffeted by two kinds of disturbances: shocks to the production function and shocks to monetary policy.

To this benchmark model, we add the assumption of sticky information. In Mankiw and Reis (2002) and Reis (forthcoming), we show that if firms are assumed to set prices based on outdated information sets, certain features of inflation dynamics are more easily explained. In Mankiw and Reis (2003), we found that sticky information on the part of workers could account for some features of the labor market. Reis (2004) discovered that inattentiveness on the part of consumers helps explain the dynamics of consumption.[1] Here we show that pervasive stickiness of this type can simultaneously help explain several features of business-cycle dynamics.

I. Three Key Facts

We focus on three key facts that describe short-run economic fluctuations. These facts are chosen because we believe they are crucial for any business-cycle theory to explain and because they are hard to square with macroeconomic models without any frictions.

Fact 1: The Acceleration Phenomenon.—In Mankiw and Reis (2002), we emphasized that inflation tends to rise when the economy is booming and falls when economic activity is depressed. This is the central insight of the empirical literature on the Phillips curve. One simple way to illustrate this fact is to correlate the change in inflation, $\pi_{t+2} - \pi_{t-2}$, with output, y_t, detrended with the HP filter.[2] In U.S. quarterly data from 1954-Q3 to 2005-Q3, the correlation is 0.47. That is, the change in inflation is procyclical.

Fact 2: The Smoothness of Real Wages.—According to the classical theory of the labor market, the real wage equals the marginal product of labor, which, under Cobb-Douglas production, is proportional to the average productivity of labor. In the data, however, real wages do not fluctuate as much as labor productivity. In particular, the standard deviation of the quarterly change in real compensation per hour is only 0.69 of the standard deviation of the change in output per hour. The real wage appears smooth relative to its fundamental determinant.

Fact 3: Gradual Response of Real Variables.—Empirical estimates of the dynamic response of economic activity to shocks typically show a hump-shaped response. The full impact of shocks

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[1] Xavier Gabaix and David Laibson (2002) and Jonathan A. Parker and Christian Julliard (2005) explored the consequences of inattentiveness for the link between consumption and asset prices.

[2] All variables in this paper are in logs and are for the nonfarm business sector. Inflation is measured by the change in the log of the implicit price deflator for this sector, which is also used to create all real variables.

is usually felt only after several quarters. One simple way to demonstrate this is to compare the standard deviation of the quarterly change in output, $\sigma(y_t - y_{t-1})$, with one-half the standard deviation of the four-quarter change in output, $\frac{1}{2}\sigma(y_t - y_{t-4})$. For a random walk, there is no hump-shaped response and these two measures are equal. In U.S. data, however, the first is only 0.79 of the second, indicating that the impact of shocks builds over several quarters.

In summary, here are the three facts on which we focus:

- $\rho(\pi_{t+2} - \pi_{t-2}, y_t - y_t^{trend}) = 0.47$.
- $\sigma[\Delta(w - p)]/\sigma[\Delta(y - l)] = 0.69$.
- $\sigma(y_t - y_{t-1})/[\frac{1}{2}\sigma(y_t - y_{t-4})] = 0.79$.

As we will see, a benchmark classical model has trouble fitting each of these facts. We can fix this problem with the assumption of pervasive stickiness of information.

II. The Model

A. *Markets and Individual Behavior*

We will use a standard general equilibrium new Keynesian model with monopolistic competition and no capital accumulation. Because the model is standard, we briefly sketch it, relegating a detailed exposition to an Appendix available at http://post.economics.harvard.edu/faculty/mankiw/mankiw.html http//www.princeton.edu/~rreis/. There are three types of agents in the economy: firms, consumers, and workers. They meet in markets for labor, goods, and savings.

The firms in the model have a monopoly over a specific product, for which the demand has a constant price elasticity, ν. Each firm operates a technology $y_{t,j} = a_t + \beta n_{t,j}$ that transforms a composite variable labor input ($n_{t,j}$) into output ($y_{t,j}$) under decreasing returns to scale ($\beta \in (0, 1)$), subject to aggregate productivity shocks (a_t).[3] Productivity follows a random walk with a standard deviation of innovations of σ_a. The composite input combines different varieties of labor supplied through a Dixit-Stiglitz aggregator with an elasticity of substitution γ.

Within each firm, there are two decision makers. The hiring department is in charge of purchasing the different varieties of labor to minimize costs. The sales department produces the good and sets the price to maximize profits. Although the hiring department acts with perfect information, the sales department faces costs of acquiring, absorbing, and processing information as in Reis (forthcoming), so it only sporadically updates its information. A firm that last updated its information j periods ago, up to a first-order approximation, sets a price

$$p_{t,j} = E_{t-j}\left[p_t + \frac{\beta(w_t - p_t) + (1-\beta)y_t - a_t}{\beta + \nu(1-\beta)}\right].$$

The firm wishes to set its price ($p_{t,j}$) relative to the aggregate of prices set by other firms (p_t) to increase with real marginal costs. Real marginal costs are higher if the real wage ($w_t - p_t$) is higher, if production (y_t) is larger because of diminishing returns to scale, and if productivity (a_t) is lower.

As in Mankiw and Reis (2002), price setters have sticky information. In each period, a fraction λ of firms, randomly drawn from the population, obtains new information and recalculates the optimal price.[4] The price level, up to a first-order approximation, then equals

$$p_t = \lambda \sum_{j=0}^{\infty} (1-\lambda)^j p_{t,j}.$$

Consumers are the second set of agents. They maximize expected discounted utility from consuming every period a Dixit-Stiglitz aggregator of the different varieties of goods the firms sell. They face an intertemporal budget constraint. The nominal interest rate is i_t, the real interest rate is r_t, and the Fisher equation holds:

$$r_t + E_t(\Delta p_{t+1}) = i_t.$$

[3] You can alternatively think of firms as operating a technology $Y_{t,j} = A_t N_{t,j}^{\beta} K_{t,j}^{1-\beta}$ where $K_{t,j}$ is a fixed endowment of capital. Since we are abstracting from capital accumulation, this is equivalent to our model with the fixed amount of firm capital normalized to one.

[4] Reis (forthcoming) provides a microfoundation for why firms would choose plans for prices and the conditions under which, in a population of firms that optimally choose to be inattentive, the arrival of planning dates has an exponential distribution.

Consumers also have two decision makers. One is a shopper who allocates total expenditures over the different varieties using full information. This leads to the constant price-elasticity demand for the product of each firm mentioned earlier. The other decision maker is a planner who allocates total expenditure over time. She faces costs of information, leading her to stay inattentive; every period a fraction of consumers, δ, update their information. Reis (2004) provides a detailed analysis and microfoundation for this behavior. A planner that last updated her information j periods earlier chooses expenditure $c_{t,j}$ to satisfy the log-linearized Euler equation

$$c_{t,j} = -\theta E_{t-j}(r_t) + \delta E_{t-j}(c_{t+1,0}) + (1-\delta)c_{t+1,j+1}.$$

The parameter θ is the elasticity of intertemporal substitution.

The consumers differ only with regard to when they last updated their plans. Total consumption, up to a first-order approximation, is therefore equal to

$$y_t = \delta \sum_{j=0}^{\infty} (1-\delta)^j c_{t,j}$$

where we used market clearing to replace total consumption with aggregate output.

Workers are the final set of agents. They share a household with consumers and also care about maximizing expected discounted utility subject to the same intertemporal budget constraint. They choose how much to work and what wage to charge for the particular variety of labor over which they hold a monopoly. The demand for their services comes from the hiring department of firms and, therefore, has a constant price elasticity of γ.

A worker who last updated her information j periods ago sets a nominal wage according to the Euler equation

$$\psi w_{t,j} = E_{t-j}\{l_{t,j} - \psi r_t + \psi p_t + \omega[\psi(w_{t+1,0} - p_{t+1}) - l_{t+1,0}] + (1-\omega)[\psi(w_{t+1,j+1} - p_{t+1}) - l_{t+1,j+1}]\}.$$

The parameter ψ measures the Frisch wage elasticity of labor supply, while ω is the probability that any worker faces of updating her plans at any date. The nominal wage ($w_{t,j}$) is higher the more labor is supplied ($l_{t,j}$) and the higher prices p_t are. As in Robert E. Lucas, Jr. and Leonard A. Rapping (1969), workers intertemporally substitute labor. The higher they expect their wage to be tomorrow, the more willing they are to work then, rather than now, and, so, the higher the wage they demand today. Likewise, if they expect to work more tomorrow, they wish to substitute part of this into work today and, thus, lower their wage demands. The last component of the intertemporal labor supply is the real interest rate. The higher r_t is, the higher the returns are for working today rather than tomorrow. This leads to an increase in the willingness to work today and, thus, lowers wage demands.[5]

The wage index equals, up a first-order approximation:

$$w_t = \omega \sum_{j=0}^{\infty} (1-\omega)^j w_{t,j}.$$

Finally, the monetary authority follows a Taylor rule:

$$i_t = \phi_y(y_t - y_t^n) + \phi_\pi \Delta p_t + \varepsilon_t.$$

The parameter ϕ_π is larger than one, respecting the Taylor principle and ensuring a determinate equilibrium for inflation. The natural level of output y_t^n denotes the equilibrium level of output if all agents were attentive (that is, if $\lambda = \delta = \omega = 1$), so policy responds to the output gap.[6] Finally, ε_t denotes policy disturbances which follow a first-order autoregressive process with

[5] If both members of a household update their information at the same time, then labor supply has the perhaps more familiar static form $\psi w_{j,t} = E_{t-j}(l_{j,t} + \psi c_{t,j})$. If workers set their wage plans at different dates from when consumers set their consumption plans, however, this condition does not hold. The two members of the household do not agree on the marginal value of an extra unit of wealth.

[6] One can show that $y_t^n = (1 + 1/\psi)a_t/(1 + 1/\psi + \beta/\theta - \beta)$.

parameter ρ and standard deviation of shocks σ_e.[7]

B. *The Reduced Form of the Model*

From the previous equations, one can obtain three equations that capture the equilibrium in the three markets of the model. The first equation is an AS relation or Phillips curve:

$$p_t = \lambda \sum_{j=0}^{\infty} (1-\lambda)^j E_{t-j} \left[p_t + \frac{\beta(w_t - p_t) + (1-\beta)y_t - a_t}{\beta + \nu(1-\beta)} \right].$$

Intuitively, the higher expected prices or marginal costs are, the higher the price firms wish to set will be. In response to an unexpected rise to these variables though, only a share λ of firms will raise their price.

The second condition is an IS equation capturing the relationship between spending and financial conditions:

$$y_t = \delta \sum_{j=0}^{\infty} (1-\delta)^j E_{t-j}(y_t^n - \theta R_t).$$

$R_t = E_t(\sum_{i=0}^{\infty} r_{t+i})$, the long real interest rate.[8] Higher expected productivity increases spending, while higher expected interest rates lower spending by encouraging saving. The stickier information is (smaller δ), the smaller the impact of shocks on spending, since fewer consumers are aware of them.

The third equation is a labor market clearing equation, or wage curve:

$$w_t = \omega \sum_{j=0}^{\infty} (1-\omega)^j E_{t-j} \left[p_t + \frac{\gamma(w_t - p_t)}{\gamma + \psi} + \frac{y_t - a_t}{\beta(\gamma + \psi)} + \frac{\psi(y_t^n - \theta R_t)}{\theta(\gamma + \psi)} \right].$$

Nominal wages increase one-to-one with expected prices because workers care about real, not nominal, wages. The more labor is used in production, the higher wages are, reflecting the standard slope of the labor supply curve. Higher expected productivity leads to higher wages. Finally, higher interest rates imply a larger return on today's saved earnings, leading to more willingness to work and lower wage demands.

These three equations combined with the Fisher equation and the Taylor rule determine a sticky information equilibrium in $(y_t, p_t, w_t, r_t, i_t)$ given exogenous shocks to (a_t, ε_t). The Appendix describes an algorithm that computes the equilibrium. We will use a baseline set of parameters. For preferences: $\theta = 1$, so utility over consumption is logarithmic; $\psi = 4$, so labor supply is very wage elastic; and $\nu = 20$, so the price markup is about 5 percent consistent with the lower end of the estimates in Susanto Basu and John G. Fernald (1995). For technology, we assume that $\gamma = 10$, so the wage markup is about 11 percent and the labor share of income $\beta = 2/3$. The Taylor rule parameters are taken from Glenn D. Rudebusch (2002): $\phi_y = 0.33$, $\phi_\pi = 1.24$, $\rho = 0.92$, and $\sigma_e = 0.0036$. Finally, based on U.S. quarterly data, we set $\sigma_a = 0.0085$. We have experimented with alternative reasonable parameter values and obtained similar conclusions, but we do not report these experiments here due to space constraints.

III. The Need for Pervasive Stickiness

A. *The Classical Benchmark*

We start with the classical model in which there is no stickiness of information. In this fully attentive economy, the classical dichotomy holds, and output is always at its natural level. Because there is no output gap, the model offers no obvious way of explaining Fact 1, the acceleration phenomenon. In this classical benchmark, output (which is driven solely by

[7] Our choices regarding inattentiveness were made in an attempt to avoid some thorny theoretical issues. For example, if shoppers were inattentive, monopolistic firms would be tempted to raise prices to take advantage of their inattentiveness. Separating consumers and firms into attentive and inattentive pieces allows us to make prices, wages, and consumption sticky at the macroeconomic level without inducing such strategic responses at the microeconomic level.

[8] All variables are in deviations from the steady state so $\lim_{i\to\infty} E_t[r_{t+i}] = 0$, and the long rate is finite. See the Appendix for more details.

productivity shocks) and inflation (which is driven solely by monetary policy shocks) are independent.

The model also cannot explain Fact 2, the smoothness of real wages: without any rigidities, real wage growth exactly equals productivity growth. Finally, output is proportional to productivity (see footnote 6). Thus, it follows a random walk, contradicting Fact 3. We therefore conclude that *this frictionless economy cannot fit any of the three facts.*

B. *Single Sources of Stickiness*

Imagine now that only firms are inattentive, updating their information on average once a year ($\lambda = 0.25$). The model can now generate an acceleration correlation of 0.56, moving in the direction of fitting Fact 1. But $\sigma[\Delta(w - p)]/\sigma[\Delta(y - l)] = 1.54$ and $\sigma(y_t - y_{t-1})/[\frac{1}{2}\sigma(y_t - y_{t-4})] = 1.03$, so the model moves in the wrong direction when it comes to fitting the other two facts.

Alternatively, suppose there is sticky information only in the labor market, with 25 percent of workers updating their plans every period ($\omega = 0.25$). The model again moves in the right direction with regard to the acceleration phenomenon, predicting a correlation between changes in inflation and the output gap of 0.10. Real wages, however, are exactly as volatile as labor productivity, and output adjusts quickly to shocks (the ratio of standard deviations is 1.17). The result concerning real wages can be derived from the Phillips curve: if goods prices are set with full attention, real wages always equal output per hour.

The last case is that of only inattentive consumers ($\delta = 0.25$). This model fails to match Fact 1 (the correlation between inflation and the output gap is almost exactly zero) and Fact 2 (real wages are just as volatile as labor productivity). Sticky information on the part of consumers helps move the model closer to the data with regard to the sluggishness of real variables. The ratio $\sigma(y_t - y_{t-1})/[\frac{1}{2}\sigma(y_t - y_{t-4})]$ is 0.65, much closer to Fact 3 on U.S. data.

C. *Two Sources of Stickiness*

What if two of the three sets of agents in the economy are inattentive, but the remaining are attentive? Again, the model cannot fit the facts. If producers are attentive, then real wages and output per hour are proportional, failing to match Fact 2 concerning the smoothness of real wages. If, instead, workers are the only agents without sticky information, then $\sigma[\Delta(w - p)]/\sigma[\Delta(y - l)] = 1.68$. In this case, real wages are more volatile than productivity, again failing to match Fact 2. Finally, if consumers are the only attentive agents, then $\sigma(y_t - y_{t-1})/[\frac{1}{2}\sigma(y_t - y_{t-4})] = 1.03$. The model with attentive consumers cannot generate Fact 3, the gradual response of real output.

D. *Pervasive Stickiness*

The previous cases showed that with either no stickiness or selective stickiness, one cannot fit all three business cycle facts. *Pervasive stickiness is necessary.* We now ask whether pervasive stickiness is itself enough to account for the facts. We start with the case where firms, consumers, and workers are all inattentive, with $\lambda = \delta = \omega = 0.25$. In this economy, $\rho(\pi_{t+2} - \pi_{t-2}, y_t - y_t^n) = 0.63$, $\sigma(\Delta(w - p))/\sigma(\Delta(y - l)) = 0.29$, and $\sigma(y_t - y_{t-1})/[\frac{1}{2}\sigma(y_t - y_{t-4})] = 0.69$. Pervasive stickiness moves the baseline classical model in the right direction across all three dimensions. Changes in inflation are now positively correlated with real activity, wages are smoother than productivity, and output adjusts gradually to shocks.

These results come from somewhat arbitrarily setting the degree of information stickiness to 0.25 for all sectors of the economy. We have searched for the values of the inattentiveness parameters λ, ω, and δ that move the model closest to fitting the three facts, in the sense of minimizing the sum of squared deviations of the model's predicted moments and their empirical counterparts. Formally, this is akin to the method of simulated moments with a GMM weighting matrix that gives each moment the same weight. The resulting estimates are $\lambda = 0.52$, $\omega = 0.66$, and $\delta = 0.36$. In this best-fitting case, firms setting prices update their information on average about every six months, workers setting wages update about every four-and-a-half months, and consumers update about every nine months. Despite this mild amount of inattentiveness and the model's simplicity, it fits the facts remarkably well: its predicted moments are within less than 0.06 of the three facts. Using the same estimation method, but assuming all agents update their plans with the same frequency, leads to an estimated probability of adjustment of 0.57, indicating that agents update their information on average every five months. In this case, $\rho(\pi_{t+2} - \pi_{t-2}, y_t - y_t^n) = 0.43$, $\sigma[\Delta(w - p)]/\sigma[\Delta(y - l)] = 0.56$, and $\sigma(y_t - y_{t-1})/[\frac{1}{2}\sigma(y_t - y_{t-4})] = 0.89$. Introducing this one free parameter moves the model significantly in the direction of explaining all three facts.

IV. Conclusion

Many modern models of business cycles start from a classical benchmark similar to the one in this paper. Over the past two decades, however, researchers have found that this model has several shortcomings and have proposed remedies. Because monetary policy seems to have real effects, research has recently focused on a hybrid formulation of Calvo's sticky-price model in which either some price setters are naive or all index their prices to past inflation. Because real wages are smooth in the data, research has looked into models with adjustment costs in using inputs, norms in labor bargaining, or direct real wage rigidities. Because consumption and output growth are positively serially correlated, research has considered modeling representative agents that form habits. In a prescient article, Christopher A. Sims (1998) noted that across all dimensions, to match the data, the classical model needed "stickiness."

It has become increasingly clear that stickiness is not just needed, but must also be pervasive. Fixing the classical model with a series of isolated patches, however, runs the risk of losing the discipline of having a model altogether. Inattentiveness and stickiness of information have the virtue of adding only one new plausible ingredient to the classical benchmark. The results reported here suggest that such a model moves promisingly in the direction of fitting the facts on business cycles.

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