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New Keynesian Economics and the Phillips Curve

STICKY PRICES are an important part of monetary models of business cycles. In recent years, a consensus has formed around the microfoundations of sticky price models, and this consensus is an important part of New Keynesian economics (Ball, Mankiw, and Romer 1988). In this paper, I show that several of the New Keynesian models, including the models of staggered contracts developed by Taylor (1979, 1980) and Calvo (1983) and the quadratic price adjustment cost model of Rotemberg (1982), have a common formulation that is similar to the expectations-augmented Phillips curve of Friedman and Phelps.

I also present new estimates of this common model. Because prices are sticky in the New Keynesian models, price setting must take into account future prices, and an important issue in estimation is how to deal with expectations about future prices. Previous estimates of these models, such as those by Taylor (1980, 1989) and Rotemberg (1982), have been based on full-information techniques, in which expectations are solved under the assumption of rational expectations. As is well known, full-information estimation has the advantage of econometric efficiency if the model is correctly specified, but the disadvantage that if any part of the model is misspecified—even a part of secondary interest—the estimates will be inconsistent.

I explored two limited-information approaches. One was the technique, introduced by McCallum (1976), of using the actual future value of a variable as a proxy and then restricting the information used in estimation—such as any instrumental variables—to what was available at the time the expectations of the variable were

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formed. This approach has the advantage over the full-information technique that the complete economic environment need not be specified.

The other limited-information approach was to use inflation expectations obtained through surveys as proxies for expectations. This approach shares with McCallum's technique the advantage that assumptions about the structure of the rest of the economy are not necessary. But survey responses may be better measures of people's expectations than are realized future prices: I find that the key parameters of the model had the correct sign regardless of the proxy for expectations, but that the estimates were more precise when I use the surveys as proxies for expectations.

1. THE MODEL

In the New Keynesian literature, models of sticky prices have been grouped into two general categories: "time-dependent" and "state-dependent" models (Ball, Mankiw, and Romer 1988). In state-dependent models, firms change prices when underlying determinants, such as demand and costs, reach certain bounds. In time-dependent models, such as the staggered contracts models of Taylor and Calvo, firms set their prices for fixed periods of time. As I will show shortly, time-dependent models can have explicit closed-form solutions relating current price changes to future price changes and the current state of demand. State-dependent models do not, in general, have simple closed-form solutions, and in some state-dependent models, such as the one analyzed by Caplin and Spulber (1987), aggregate price adjustment may be instantaneous even if individual prices are sticky. As a consequence, I focus on time-dependent models.

1a. The Quadratic Price Adjustment Cost Model

In Rotemberg's (1982) framework, firms minimize the costs of changing prices, weighed against the costs of being away from the price the firm would choose in the absence of adjustment costs:[1]

$$\min_{(p)} \Omega_t = E_t \sum_{\tau=t,\infty} \theta^{\tau-t} [(p_\tau - p^*_\tau)^2 + c(p_\tau - p_{\tau-1})^2] , \qquad (1)$$

where Ω is total cost, p is the log of the actual price at time t, p^* is the (log of the) price a firm would charge in the absence of adjustment costs, θ is a constant discount factor, and c is a parameter that measures the ratio of the costs of changing prices to the costs of being away from the optimum price.

The first-order condition of this problem is

1. Although Rotemberg's model is not strictly time dependent, its implications are similar to those of the time-dependent models, as I will show shortly. The similarity among these models has been noted before. Calvo (1983) pointed out that the implications of his model are similar to those of Taylor's, while Rotemberg (1987) noted the similarity between his model and Calvo's.

$$E_t\{(p_t - p_t^*) + c[(p_t - p_{t-1}) - \theta(p_{t+1} - p_t)]\} = 0 . \tag{2}$$

Assume that the discount rate, θ, is equal to one; for high frequency data, this is approximately correct. Then we have

$$\Delta p_t = E_t \Delta p_{t+1} - (1/c)\,(p_t - p_t^*) .$$

One way to specify p^* is

$$p_t^* = \hat{p}_t + \beta y_t + \epsilon_t ,$$

where y is the percent deviation of aggregate output from its trend, $\hat{p}$ is the price charged by other firms, ϵ is an i.i.d. random error term, and β is a positive parameter. This equation assumes that the firm has an upward-sloping supply curve, so that it wants to raise its price if demand is high (for example, when aggregate income is high).

Using this specification for p^*, and assuming that all firms are identical, so that $p = \hat{p}$, equation (2) becomes

$$\Delta p_t = E_t \Delta p_{t+1} + (\beta/c)\, y_t - \epsilon_t/c . \tag{3}$$

As discussed in section 1d, equation (3) is a type of expectations-augmented Phillips curve. Future inflation appears because prices are sticky, which means that the behavior of prices in the next period is important in determining current prices. Note that the coefficient on y is positive, because β and c are positive.

1b. Calvo's Staggered Contracts Model

In Calvo's (1983) model, each firm keeps its price fixed until it receives a random signal that it can change its price. Price changes are therefore "staggered," and when setting prices, the firm takes into account the prices other firms will charge until it has a chance to change prices again. And because the prices of other firms were set in the past, the firm takes into account past prices in setting current ones.

The probability that a firm will receive a signal in any particular time period is π.[2] Let's assume that there are enough firms so that π also represents the fraction of firms that can change prices in any period. Firms are assumed to have upward-sloping supply curves. The firm therefore chooses its price z_t so that

$$z_t = \pi\, E_t \sum_{j=0,\infty} (1 - \pi)^j (p_{t+j} + \beta y_{t+j} + \epsilon_{t+j}),$$

2. Calvo derived his model in continuous time. To draw the comparison with the other models more clearly, I use Rotemberg's (1987) discrete-time characterization of Calvo's model.

where, as in the previous example, β is a positive constant. The aggregate price level will be

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

Assuming ϵ_t is observable in period t, these two equations imply the following equations of motion:

$$z_t = \pi(p_t + \beta y_t + \epsilon_t) + (1 - \pi) E_t z_{t+1}$$

and

$$p_t = \pi z_t - (1 - \pi) p_{t-1} .$$

From these, we have

$$E_t \Delta z_{t+1} = \pi E_t z_{t+1} - \pi(p_t + \beta y_t + \epsilon_t) \tag{4}$$

and

$$\Delta p_t = \pi z_t + \pi p_{t-1} . \tag{5}$$

Together, these equations imply

$$E_t \Delta z_{t+1} = E_t \Delta p_{t+1} - \pi\beta y_t - \pi\epsilon_t . \tag{6}$$

Differencing equation (4) and leading one period gives

$$E_t \Delta z_{t+1} = (1/\pi) [E_t \Delta p_{t+1} + (\pi - 1) \Delta p_t] .$$

Substituting into (5) and rearranging gives

$$\Delta p_t = E_t \Delta p_{t+1} + (\pi^2 \beta)/(1 - \pi) y_t + \pi^2/(1 - \pi) \epsilon_t . \tag{7}$$

Again, we have an expectations-augmented Phillips curve. Again, the coefficient on output is positive, as desired, because $\beta > 0$ and π is between zero and one.

1c. Taylor's Staggered-Contracts Model

In Taylor's (1979) model, wages are assumed to be set for two periods, so the average wage to the firm is

$$w_t = (x_t + x_{t-1})/2 ,$$

where w is the average, observable wage and x is the contract wage, chosen in period t, for the periods t and $t+1$. The variables w and x refer to logarithms.

Workers are assumed to be concerned about real wages and unemployment over the life of their contract. The labor supply curve is therefore

$$x_t - (p_t + E_t p_{t+1})/2 = c_0 - \beta(RU_t + E_t RU_{t+1})/2 + \epsilon_t ,$$

where p is the log of price, RU is the unemployment rate, ϵ is a white-noise error term capturing various unobserved determinants of wages, and c_0 and β are constants. $\beta > 0$, so higher unemployment is associated with lower wages.

The firm sets prices as a constant markup over wages. Normalizing the markup to zero,

$$p_t = w_t .$$

In this model, wages are the only source of nominal rigidity. This feature makes the model an interesting contrast to the first two, which are based on sticky prices.

The preceding three equations can be combined to form:

$$\begin{aligned}\Delta p_t = E_t \Delta p_{t+1} + c_0 - \beta(RU_{t-1} + RU_t + E_{t-1}RU_t + E_t RU_{t+1}) \\ + 2(\epsilon_t + \epsilon_{t-1}) + \eta_t , \qquad (8)\end{aligned}$$

where η is an expectational error $(E_{t-1}p_t - p_t)$. Once again, we have essentially an expectations-augmented Phillips curve. Again, the coefficient on the "real activity" variable has the expected sign: When a moving average of unemployment rises, inflation falls. Here, the residual error term has a moving-average component.

1d. The New Keynesian Phillips Curve

A common formulation that captures the key element of equations (4), (7), and (8) is

$$\Delta p_t - E_t \Delta p_{t+1} = c_0 + \gamma y_t + \epsilon_t , \qquad (9)$$

where ϵ is a residual error term, which may be serially correlated, and γ is a positive constant. The relationship of equation (9) to Rotemberg's and Calvo's models is clear. The following argument makes the connection between equation (9) and Taylor's model: Because the unemployment rate is strongly serially correlated, current unemployment is an adequate proxy for the current, lagged, and future unemployment. Okun's law can be applied to move from unemployment and output. Finally, Taylor's model implies that the residual in equation (9) has a moving-average component.

Equation (9) is similar to the expectations-augmented Phillips curve of Friedman and Phelps. The contribution of the New Keynesian models in interpreting the Phillips curve is to emphasize the role of explicit nominal rigidities in interpreting the model, since in the models of sections 1a, 1b, and 1c, outcomes in labor and product markets would be classical in the absence of rigidities.

Equation (9) is also similar to the Lucas supply curve (Lucas 1973). The two differ in that equation (9) includes expectations of next period's inflation, whereas Lucas's supply curve incorporates expectations of current inflation. The reason future inflation matters in the New Keynesian model is that prices are sticky.

Because changes in real oil prices are an important and readily identifiable source of ϵ variation, I made a slight modification to equation (9):

$$\Delta p_t - E_t \Delta p_{t+1} = c_0 + \gamma\, y_t + c_1\, \Delta rpoil_t + c_2\, \Delta rpoil_{t-1} + \epsilon_t\,,$$

where *rpoil* is the log of the real price of crude oil and c_1 and c_2 are constants. I also estimated equations using the unemployment rate in place of the gap between actual and trend GNP. The unemployment rate is an alternative indicator of overall economic activity, and if we view labor markets as central to aggregate nominal rigidity, as they are in Taylor's model, then unemployment may be a superior indicator. Thus, I also explored equations of the form

$$\Delta p_t - E_t \Delta p_{t+1} = c_0 - \gamma' RU_t + c_1\, \Delta rpoil_t + c_2\, \Delta rpoil_{t-1} + \epsilon_t\,.$$

2. PROXIES FOR EXPECTATIONS AND OTHER DATA ISSUES

I used two types of proxies for expected inflation. One approach was to use surveys of price expectations. Two surveys of one-year-ahead inflation expectations have been conducted for many years: The Michigan Survey Research Center, in its periodic surveys of consumer attitudes, asks individuals what they expect inflation to be over the coming year.[3] And a survey of business economists, called the Livingston survey after its originator, is conducted by the Federal Reserve Bank of Philadelphia. Surveys have their limitations, however, the main one being that respondents have little incentive to provide thoughtful answers. To the extent this is a problem, the surveys may be poor proxies for actual expectations and there will be a degree of noise introduced in the estimation.

In the second approach, introduced by McCallum (1976), the actual future value of inflation is used as a proxy for the expectation:

$$\Delta p_t - \Delta p_{t+1} = c_0 + \gamma y_t + \epsilon_t + (E_t \Delta p_{t+1} - \Delta p_{t+1})\,.$$

This approach has been popular in macroeconometric work because explicit measures of expectations are not needed. However, it introduces econometric complica-

3. Before 1966, the Michigan survey asked only about the future direction of inflation; numerical values for the expectations were inferred by Noble and Fields (1982).

tions, since there is an additional source of error, $v_t = (E_t\Delta p_{t+1} - \Delta p_{t+1})$, that the equations that use the surveys as expectations proxies do not have, if the surveys are good proxies for actual expectations. As a consequence, the estimates based on McCallum's technique may be less precise than those that use the surveys as measures of expectations.

Turning to other data issues, I used the twelve-month percent change in the consumer price index measured from December to December as my measure of Δp_t. This measure of inflation matches the inquiries in the Michigan and Livingston surveys. I use the producer price index for crude petroleum deflated by the GNP deflator as my measure of real crude oil prices (*rpoil*).

I measured y as the percent deviation of real GNP from a deterministic trend. The trend is estimated by regressing the log of GNP on time and time squared. While much research has focused on the potential importance of a unit root in GNP, Rudebusch (1993) and Christiano and Eichenbaum (1990) have shown that, in practice, it is difficult to distinguish between a deterministic trend and a stochastic one. And Perron (1989) has shown that a linear trend with one break in the slope of the trend will render GNP stationary. I used a quadratic trend because it is a simple way to introduce an additional degree of freedom in the trend without having to choose a break point.

To allow for the possibility that the ϵ shocks could be correlated with output, I estimated using instrumental variables. Changes in the real price of crude oil served as instruments for themselves. I used two variables as instruments for output: the current and lagged level of real government purchases of goods and services, detrended with the same trend used for output, and a dummy variable that is equal to one when a Democrat is president. These are valid instruments, since government spending is largely determined by exogenous events, such as the need to fight a war or to expand schools. And although there is some indication that economic conditions can affect the outcome of presidential elections, this effect is on the likelihood of a change in party and not on the political party of the winner. The instruments explained about 25 percent of the variation in detrended output.

Since the surveys were for one-year-ahead inflation expectations, I used annual data. The estimation period was from 1949 to 1990.

3. RESULTS

The results are shown in Table 1. The main parameter of interest, γ, has the expected sign, regardless of which proxy was used for inflation expectations and whether output or the unemployment rate was used as the measure of economic activity. It is statistically significant using both the Livingston and Michigan survey proxies, with either economic activity variable.

The estimate of γ based on McCallum's proxy is about the same size as the survey-based estimates, but it is not significant because the estimated standard error is larger, both on the coefficient estimate and on the equation as a whole. One expla-

TABLE 1

ESTIMATES OF NEW KEYNESIAN PHILLIPS CURVE, 1949 TO 1990

	Detrended output			Unemployment rate		
	Proxy for inflation expectations			Proxy for inflation expectations		
	Livingston	Michigan	McCallum	Livingston	Michigan	McCallum
Constant	.765*	.141	−.292	3.05*	1.53	1.42
	(.255)	(.290)	(.523)	(.63)	(.90)	(1.92)
γ	.337*	.249*	.355	−.401*	−.244*	−.299
	(.081)	(.077)	(.226)	(.095)	(.127)	(.384)
c_1	.050*	.041*	.041*	.059*	.048*	.053*
	(.012)	(.014)	(.012)	(.012)	(.013)	(.004)
c_2	.027*	.019*	.064*	.026*	.017*	.060*
	(.008)	(.009)	(.028)	(.007)	(.009)	(.026)
S.E.R.	1.13	1.37	2.68	.91	1.34	2.47
R^2	.48	.27	−.02	.66	.31	.13
Autocorrelations						
1	.59	.48	.34	.34	.36	.22
2	.08	.07	−.04	−.23	−.05	−.18
3	−.15	−.05	−.05	−.27	−.02	−.07
4	−.18	−.11	−.03	−.14	−.05	−.03
Godfrey tests						
First order (t−test)	11.2*	7.5*	2.6*	10.2*	4.6*	1.9
Orders 2–4 (Significance level)	.19	.82	.87	.13	.60	.95

*Significant at the 5 percent level.

nation for the larger standard error is that actual future inflation is a worse proxy for inflation expectations than are the surveys.

The coefficient on oil prices is statistically significant and is consistent with the share of oil and oil substitutes in the production of consumer goods.

The bottom part of the table shows autocorrelation statistics. The first four autocorrelations indicate strong serial correlation at the first lag, but not for higher orders of serial correlation. This impression is confirmed by the Godfrey tests for first-order and for second- through fourth-order serial correlation.[4] This pattern suggests a first-order moving-average error process. Such an error structure is compatible with the staggered-contracts version of the underlying model. The coefficient standard errors reported in the table have been adjusted to take into account the first-order serial correlation.

I also tested for subsample stability of the parameter estimates; results are available in a working paper (Roberts 1992). Subsample stability tests are particularly important for this model because, as Ball, Mankiw, and Romer (1988) have suggested, γ may depend on the expected inflation rate. The results using the survey proxies were similar across the two subsamples. The results using McCallum's proxy were qualitatively quite different in the two subsamples, but the results were not precise enough to produce a rejection at conventional confidence levels. These results suggest that the New Keynesian Phillips curve is structurally stable despite

4. I used the Godfrey test for serial correlation because it is valid under instrumental variables estimation (Godfrey 1991, ch. 5). To implement the test, I introduced lagged residuals from the reported equations as explanatory variables in a test equation, using lagged dependent variables as instruments.

the substantial difference in average inflation in the two parts of the sample (before and after 1973). These results suggest that the changes in inflation did not lead to a change in γ and indicate that the estimates of γ can be considered "structural," at least for the range of inflation rates over the past forty years in the United States.

4. INTERPRETING THE MAGNITUDE OF γ

Based on the results of Section 3, the value of γ was in the range of 0.2 to 0.4 for the deviation of actual output from trend and from -0.2 to -0.4 for the unemployment rate. What do these estimates imply in terms of the underlying microeconomic structures described in section 1? Calvo's model provides the richest interpretation. In Calvo's model, γ is $(\pi^2\beta)/(1 - \pi)$. So, γ is positively related to both β—the firm's supply elasticity—and π—the frequency of price change. It is not possible to disentangle these parameters, but some examples illustrate the trade-offs implied by the estimates. If we assume that π is $1/2$, so that $1/2$ of firms change their price each year, a γ estimate of $1/4$ (from an equation using detrended output) implies an elasticity of the firm's supply curve of $1/2$. Thus, a 1 percentage point increase in expected demand would lead to a $1/2$ percent increase in the firm's price relative to the prices set by competitors. If a larger fraction of firms changed prices each year—say, 90 percent—then a γ of $1/4$ would imply a supply elasticity of $1/32$, a much flatter supply-curve slope.[5]

Microeconomic evidence suggests that the latter interpretation may be closer to the correct one: Roberts, Stockton, and Struckmeyer (1994), looking at industry data, and Kashyap (1990) and Carlton (1986), looking at firm-level data, found that prices are changed with relative ease; Roberts, Stockton, and Struckmeyer also found quite flat marginal cost. This interpretation is also consistent with the New Keynesian model of Ball and Romer (1990), in which flat supply schedules play as important a role in creating aggregate nominal rigidity as does a reluctance of firms to change their prices.

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5. In Taylor's model, a γ (for unemployment) of $1/3$ would be consistent with a slope of the labor supply schedule that corresponds to an elasticity of about $1/12$. Thus, under the degree of rigidity chosen for the Taylor interpretation, there is also a very flat aggregate supply curve. In Rotemberg's model, γ is β/c and therefore involves the inverse of the supply elasticity of the typical good (β) and the ratio of the costs of changing price to the cost of being away from the optimum price (c). Unfortunately, c does not have a natural interpretation.

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