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Inflation Dynamics: Combining Measurement with Theory

Jordi Galí and Mark Gertler*

Among the central issues in macroeconomics is the nature of short-run inflation dynamics. This matter is also one of the most fiercely debated, with few definitive answers available after decades of investigation. At stake, among other things, is the nature of business fluctuations and the appropriate conduct of monetary policy. How a central bank should go about engineering a disinflation, for example, depends critically on the extent to which: 1) there may be a short-run tradeoff between inflation and real activity and 2) expectations of future economic activity affect current price setting behavior. The issue is also highly relevant in the current era of low inflation: how to manage monetary policy to avoid deflation and potentially slipping into a liquidity trap (of the type many observers believe is happening in Japan) is similarly sensitive to how inflation is determined in the short run.

Our research over the past few years has focused on both theoretical and empirical analysis of inflation dynamics. In contrast to much of the important traditional work on the Phillips curve, which was largely empirical in nature, we explicitly employ economic theory to develop an econometric model of inflation. By tying the empirical analysis tightly to theory, we believe we are able to obtain a deeper understanding of what determines inflation in the short run than would be the case from just examining statistical relationships. In addition, by estimating an explicit economic model, we can potentially understand how significant structural changes might affect inflation better than a mainly empirical approach would permit. Examples of significant structural changes include

shifts in trend productivity and changes in the monetary policy regime.

The New Keynesian Phillips Curve

Our work builds on the optimization-based approach to modeling short-run inflation dynamics that has been used increasingly in applied work in recent years. This literature, in turn, is an outgrowth of early theoretical work by Fischer¹, Taylor², Calvo³ and others that emphasized staggered nominal wage and price setting by forward looking workers and firms. The modern literature extends this earlier work by casting the price setting decision within an explicit individual optimization problem. Aggregating over individual behavior then leads, typically, to a relationship between inflation in the short run and some measure of overall real activity, in the spirit of the traditional Phillips curve. The explicit use of micro-foundations, of course, places additional structure on the relationship and further leads to some important differences in detail.

A canonical version of this kind of Phillips curve — often referred to as the New Keynesian Phillips Curve (NKPC) — is attributable to Calvo. This approach involves making assumptions that greatly simplify the aggregation of individual price setting, but still retain the feature of non-synchronized multi-period price setting. Because it results in a reasonably parsimonious aggregate relation for inflation, the model has gained widespread attention. It also has generated some controversy, as we discuss below.

There are two basic building blocks to the Calvo variant of the NKPC. The first is an equation that relates current inflation to two factors: the percent deviation of real marginal cost (averaged across firms) from its steady state; and expected future inflation. This relation is obtained as a log-linear approximation of the aggregated behavior of

individual firms that set prices for multiple periods based on current and anticipated future nominal marginal cost, and do so on a staggered basis.

The second key building block is an equation that has real marginal cost vary proportionately with the output gap, where the latter is defined as the percent deviation of output from its natural (flexible price equilibrium) level. This second relation holds explicitly in the model under certain auxiliary assumptions, including in particular the assumption of competitive labor markets. Intuitively, periods of excess demand (output above the natural level) are associated with marginal cost above average, and the reverse is true for periods of excess supply.

Combining these fundamental relations yields the baseline NKPC: inflation depends on the output gap and anticipated future inflation. Note that the NKPC has some of the flavor of a traditional Phillips curve in the sense that inflation varies positively in the short run with the output gap. The similarity stops there, however. The defining property of the baseline NKPC is the forward looking nature of inflation dynamics. The NKPC is effectively a first-order forward-looking difference equation in inflation with the output gap as the forcing variable. Iterating this relation forward yields inflation equal to a discounted sum of current and expected future output gaps. Intuitively, the theory suggests that price adjustment is based on current and anticipated marginal cost. Under certain conditions, the output gap proxies movements in marginal cost. Hence, inflation depends on the expected future path of the output gap, as well as on its current value.

This forward-looking behavior of inflation contrasts sharply with the traditional Phillips curve (TPC), where inflation is an entirely backward looking phenomenon.⁴ With the TPC, inflation depends on the output gap and an arbitrary number of lags of inflation. In contrast to the NKPC,

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the exact specification, of course, is not explicitly guided by theory. Also, the TPC rules out the possibility that beliefs about the future may affect current price setting and, hence, inflation.

The extent to which the NKPC captures reality has important policy implications. If expectations of the future matter, then current inflation will depend not only on prevailing economic conditions but also on beliefs about future conditions, including the future course of monetary policy. As a consequence, establishing the credibility of intentions about the future course of monetary policy becomes an important dimension of its conduct. As recent literature has shown, with forward looking price setting, establishing a credible commitment to maintaining price stability in the future reduces the cost of doing so in the present. Roughly speaking, in this context establishing credibility improves the short-run output-inflation trade-off. Note that this gain from credibility does not depend on having a central bank that wishes to push output above the natural level, as is critical in the early literature on credibility. Rather, it is a product of the forward-looking nature of price setting.⁵

The issue is also relevant to current discussions of the liquidity trap. As emphasized by Krugman,⁶ Eggertson and Woodford⁷ and others, with forward looking price setting, an economy constrained by the zero interest rate bound may be able to nonetheless stimulate economic activity by committing to inflate in the future.

Early Criticisms of the NKPC

As is now well known, the baseline NKPC, which links inflation to the output gap and expected future inflation, is at odds with the data. Estimates of this equation have the output gap enter either insignificantly or with the wrong sign. The basic problem is that the theory suggests that inflation should anticipate movements in the output gap. In the data, the reverse appears true, at least using ad hoc measures of the output gap based on simple detrending methods, that is, the

output gap tends to lead inflation.⁸ One possibility is that detrended output might not be a good proxy for the output gap, particularly if there is considerable variation in the true natural level of output. However, it appears that it would take a somewhat peculiar pattern of measurement error in the natural level of output for the model to fully account for the timing evidence on detrended output versus inflation observed in the data.

Mankiw⁹ emphasizes a closely related criticism: The identified VAR literature suggests that an anticipated tightening of monetary policy produces a decline in output after two to three quarters, but no decline in inflation until nearly a year after a shock. Simulations of models that use the NKPC may get the output response correct, but produce too early and too strong a response of inflation. Again, the problem is that inflation anticipates the output gap in the NKPC but not in the data. More generally, the NKPC has difficulty accounting for the apparent history dependence of inflation in the data. The TPC addresses this issue by simply adding lags of inflation to the right hand side of the equation. Of course, there is no underlying theoretical motivation.

A Hybrid NKPC: Development and Structural Estimates

Our work addresses the basic empirical shortcomings of the NKPC. In Galí and Gertler¹⁰ we build on the basic Calvo model and develop a new econometric framework for estimating a structural equation describing the dynamics of inflation. We start from the view that the canonical version of the model suggests that inflation should be related to movements in real marginal cost, and not to the output gap per se. It is only under the strong assumption of frictionless labor markets that the output gap should vary proportionately with marginal cost. With labor market rigidities (for example, stickiness in either nominal or real wages) this relation will not hold. Put differently, one reason for the empiri-

cal failure of the baseline model may be that the output gap is not a good proxy for marginal cost, rather than the canonical model of staggered forward price setting being incorrect. This leads us to estimate the canonical version of the model that links inflation directly to real marginal cost.¹¹

Further, we allow for the possibility that price setting is not purely forward looking. In particular, in our paper we introduced a fraction of firms in the model that adjust prices using a simple backward looking rule of thumb. The rule has the property that it converges to the optimal forward looking pricing policy rule in the steady state. The net result is a hybrid of the NKPC that nests the pure forward looking model as a special case.¹² Under our hybrid formulation, inflation depends on real marginal cost and a linear combination of expected future and lagged inflation.¹³ The model coefficients, further, are explicit functions of the primitive parameters, including the frequency of price adjustment and the fraction of firms that are backward looking. Lagged inflation disappears in the limiting case where the fraction of rule-of-thumb firms goes to zero and the model converges to the pure forward looking NKPC.

We estimate our hybrid NKPC using Generalized Method of Moments (GMM) with lagged variables as instruments (thus allowing for the possibility of measurement error.) Three principle findings emerge: 1) the coefficient on real marginal cost is positive and statistically significant; 2) the coefficient on lagged inflation is positive and statistically significant, implying that the pure forward looking model is rejected by the data; 3) forward looking behavior is still dominant across a range of estimates. The coefficients on expected future and lagged inflation generally sum to one, with the coefficient on lagged inflation ranging between 0.2 and 0.4. In subsequent work with David López-Salido¹⁴, we broadly confirmed these estimates, although we have tightened the coefficient estimates to roughly 0.35 for lagged inflation and 0.65 for expected future inflation. In addition, we show that the simple theory-based model does a reasonable job of capturing the

movements in inflation over the past forty years, including: the rise to double digit inflation in the 1970s; the disinflation of the early 1980s; and the period of simultaneous high output growth and low inflation during the latter half of the 1990s.

As some further confirmation on the empirical plausibility of our model, we obtain sensible estimates of the degree of price rigidity. From our estimates of the slope coefficients of the hybrid NKPC, we can use the underlying theory to back measures of how long prices are fixed on average. Our early work suggested a period of 4 to 5 quarters, which is high relative to the survey evidence. In subsequent work we found that after relaxing some of the technological assumptions of our model, our estimates of the average duration of a price being fixed fell to about two and a half quarters, clearly in the range of what recent survey evidence suggests.¹⁵ When applying the same approach to euro area data, we obtain similar results: the hybrid version of the NKPC seems to fit the European data equally well, if not better. Some differences emerge: the estimates of average price duration (between four and six quarters) are a bit higher than in the United States, but the forward-looking component is, if anything, even more dominant than in the United States.

It is clearly a virtue of our approach that we are able to obtain estimates of the degree of price rigidity. One potential shortcoming, though, is that we have to assume that the average time interval over which firms keep price fixed remains constant over the sample. Put differently, our model assumes time dependent price setting (where the time period remains constant) as opposed to state dependent pricing (where firms face fixed costs of changing price but with the time interval between adjustments endogenous.)¹⁶ Our implicit assumption is that variation in macroeconomic conditions (particularly inflation) is not sufficiently large to systematically affect the interval over which firms change prices. In this case, the relatively simple time-dependent model may be thought of as a reduced form approximation of the more complex

state-dependent model.

As a check on whether this assumption is reasonable, we explored the robustness of our estimates of the degree of price rigidity to different sub-samples. We found the estimates to be reasonably stable, suggesting that our assumption of time-dependent price setting may be plausible for a country like the United States that has experienced moderate variation in inflation. Clearly it would not be reasonable for a country that has experienced high and volatile inflation, such as Brazil, or Argentina.

Overall, our estimates of the hybrid NKPC appear reasonably robust to different estimation strategies.¹⁷ For example, our results are largely invariant to estimating the closed form of the model (obtained by solving out for expected inflation). Nor are they the product of weak instruments. In addition, while we have used a single equation/instrumental variable approach, a number of other papers have obtained very similar results to ours using a full blown systems approach.¹⁸

Overall, the clear message from our work is that while the pure forward looking version of the NKPC may be rejected by the data, the hybrid variant with a dominant role for forward looking behavior does reasonably well. It is in this respect that the NKPC provides useful insights into the nature of inflation dynamics and, along with it, useful insights for the conduct of monetary policy.

The NKPC and Inflation Persistence

How does the hybrid NKPC account for the apparent high degree of persistence of inflation in the data? Two factors are key: the relatively modest amount of lagged inflation (certainly as compared to the TPC) and the persistence of real marginal cost. Regarding the latter: under the assumption of Cobb-Douglas technology, real marginal cost corresponds to real unit labor costs: the real wage divided by average labor productivity. In the data, real unit labor costs are highly persistent and highly correlated

with inflation. Given that firms are pricing based on current and anticipated real unit labor costs, the sluggishness in this variable helps account for the persistence in inflation.

Note too that this approach provides a theoretically cogent way to capture the influence of supply shocks on inflation. Here supply shocks (for example, shift in oil prices or shift in total factor productivity) affect inflation by influencing the measure of firms' real marginal cost. In the Cobb-Douglas case, these shocks affect marginal cost by changing average labor productivity. For example, in the late 1990s, the surge in productivity (in conjunction with only mild real wage growth) led to a decline in unit labor costs relative to trend. For this reason, our model is able to capture the low inflation of this period reasonably well.

A complete story of short-run inflation dynamics requires modeling the evolution of real marginal cost. It appears that much of the persistence in real marginal cost (at least as measured by real unit labor cost) is associated with sluggishness in the evolution of real wages. Whether this sluggishness is attributable to stickiness in nominal or real wages is an open question. Several authors have shown that extending models similar to ours to allow for staggered nominal wage setting holds promise.¹⁹ Indeed a variation of this model that allows for wages to be indexed to past inflation appears to do well empirically. Among other things, this model of staggered wage and price setting captures very well the response of inflation to a monetary policy shock, thus providing a direct response to the Mankiw critique. We are currently exploring how well the model captures the overall variation of postwar inflation.

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² J. Taylor, "Aggregate Dynamics and Staggered Contracts," *Journal of Political Economy*, 88 (1) (1980), pp. 1-24.

³ G. A. Calvo, "Staggered Prices in a Utility Maximizing Framework," *Journal of Monetary Economics*, 12 (1983), pp. 383-98.

⁴ For examples of the traditional Phillips curve, see R. J. Gordon, "Foundations of the Goldilocks Economy," *Brookings Papers on Economic Activity*, Vol. 2 (1998), pp. 297-346, and J. H. Stock and M. W. Watson, "Forecasting Inflation," *Journal of Monetary Economics*, Vol. 44 (2001) pp. 293-335.

⁵ R. C. Clarida, J. Galí, and M. Gertler, "The Science of Monetary Policy: A New Keynesian Perspective," *Journal of Economic Literature*, Vol. 37 (1999), pp. 1661-707; J. Galí, "New Perspectives on Monetary Policy, Inflation, and the Business Cycle," NBER Working Paper No. 8767, February 2002, and in *Advances in Economics and Econometrics*, Vol. III, M. Dewatripont, L. Hansen, and S. Turnovsky, eds., Cambridge: Cambridge University Press, 2003; M. Woodford, "Optimal Monetary Policy Inertia," NBER Working Paper No. 7261, July 1999.

⁶ P. R. Krugman, "It's Baaack! Japan's Slump and the Return of the Liquidity Trap," *Brookings Papers on Economic Activity*, Vol. 2 (1998), pp. 137-87.

⁷ G. Eggertson and M. Woodford, "The Zero Bound on Interest Rates and Optimal Monetary Policy," *mimeo*, 2003.

⁸ See, for example, J. C. Fubrer and G. Moore, "Inflation Persistence," *Quarterly Journal of Economics*, Vol. 440 (February 1995), pp. 127-59, or J. Galí and M. Gertler, "Inflation Dynamics: A Structural Econometric Analysis," *Journal of Monetary Economics*, Vol. 44 (2) (1999), pp. 195-222.

⁹ N. G. Mankiw, "The Inexorable and

Mysterious Tradeoff Between Inflation and Unemployment," *Economic Journal*, 117 (2001), pp. 1295-328.

¹⁰ J. Galí and M. Gertler, "Inflation Dynamics: A Structural Econometric Analysis."

¹¹ See also A. Sbordone, "Prices and Unit Labor Costs: Testing Models of Pricing Behavior," *Journal of Monetary Economics*, Vol. 45 (2) (2002), pp. 265-92, which pursues a similar approach, though using a different econometric methodology.

¹² As Christiano, Eichenbaum, and Evans observe, one can obtain an equivalent formulation by introducing lagged indexing, as opposed to the rule of thumb price setting. See L. Christiano, M. S. Eichenbaum, and C. Evans, "Nominal Rigidities and the Effects of a Shock to Monetary Policy," *mimeo*, 2001.

¹³ Fubrer and Moore earlier proposed a hybrid model. Ours differs by having real marginal cost as the forcing variable and also having the slope coefficients derived as explicit functions of the primitive parameters. Our formulation leads to a more important role for forward-looking behavior. See J. Galí and M. Gertler, "Inflation Dynamics: A Structural Econometric Analysis;" J. Galí, M. Gertler, and D. López-Salido, "Robustness of The Estimates of the Hybrid Version of the New Keynesian Phillips Curve," *mimeo*, 2003; and J. C. Fubrer, "The (Un)Importance of Forward-Looking Behavior in Price Setting," *Journal for Money, Credit and Banking*, 29 (August 1997), pp. 338-50.

¹⁴ J. Galí, M. Gertler, and D. López-Salido, "European Inflation Dynamics,"

European Economic Review, Vol. 45(7) (2001), pp. 1237-70.

¹⁵ See, for example, M. Bils and P. Klenow, "Some Evidence on the Importance of Sticky Prices," *mimeo*, 2002.

¹⁶ For models of state-dependent pricing, see A. Caplin and J. Leahy, "State-Dependent Pricing and the Dynamics of Money and Output," *Quarterly Journal of Economics*, 106 (1991), pp. 683-708, and M. Dotsey, R. G. King, and A. Wolman, "State-dependent Pricing and the General Equilibrium Dynamics of Money and Output," *Quarterly Journal of Economics*, 114 (2) (1999).

¹⁷ J. Galí, M. Gertler, and D. López-Salido, "Robustness of The Estimates of the Hybrid Version of the New Keynesian Phillips Curve."

¹⁸ L. Christiano, M. S. Eichenbaum, and C. Evans, "Nominal Rigidities and the Effects of a Shock to Monetary Policy;" P. N. Ireland, "Sticky Price Models of the Business Cycle: Specification and Stability," *Journal of Monetary Economics*, Vol. 47 (1) (2001), pp. 3-18; F. Smets and R. Wouters, "An Estimated Dynamic Stochastic General Equilibrium Model of the Euro Area," *Journal of the European Economic Association*, forthcoming.

¹⁹ For an alternative approach, based on sticky information, see N. G. Mankiw and R. Reis, "Sticky Information versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve," *Quarterly Journal of Economics*, 117 (November 2002), pp. 1295-328.