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MODELING THE PHILIPS CURVE: A TIME-VARYING VOLATILITY APPROACH

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Abstract

This paper examines the Phillips curve relationship when the second moment of inflation is nonlinear. Specifically, we estimate GARCH models that provide evidence consistent with Keynesian-type models that imply output "overshooting" and inflation fluctuations following aggregate demand shocks. Additionally, the evidence suggests that an increase in the conditional variability of inflation leads to higher levels of inflation.

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1. Introduction

The relationship between prices and output is a central theme in both theoretical and empirical macroeconomics. For example, many Keynesian-style models are based on the notion of prices being sticky. In traditional models of this type, aggregate demand shocks may lead to changes in output that are then characterized by a return to potential or equilibrium output that is less than smooth. This adjustment process is often predicated on a variant of the expectations-augmented Phillips curve and suggests that output and inflation will fluctuate during the period before long-run equilibrium is attained. However, it may be the case that the fluctuations in inflation are predictable or time varying and, if so, empirical models of the Phillips curve should take this behavior into account.

Furthermore, a number of recent papers have suggested that inflation and its volatility may be linked, with increases in inflation variability corresponding to higher levels of inflation. In this paper, we reexamine the relationship between inflation and the deviation of output from its potential using a time-series technique that is capable of handling the time-varying volatility in inflation that is suggested by Keynesian-type models. The main purpose of this research is to determine whether or not incorporation of the time-varying volatility of inflation provides meaningful information to the standard expectations-augmented Phillips curve. Results of this study will provide useful information to policymakers, as well as to our general understanding of the macroeconomic relationships embedded in the Phillips curve. Specifically, we estimate a nonlinear-in-variance model of the U.S. Phillips curve over a substantially long time frame that begins in the mid-1950s and ends in 1999. This should be particularly interesting to policy-oriented macroeconomists as this technique provides more accurate parameter estimates of the weights placed on the output gap and expected inflation in the Phillips curve.

From a historical perspective, it is interesting to note that during the 1960s, US economic policy centered on the ability of a policy-maker to gradually obtain a lower unemployment rate by moderately increasing the inflation rate. However, it was soon recognized that unemployment could not persist below its natural rate without resulting in accelerating inflation. In fact, economic theory suggests that when output exceeds its potential level, shortages of workers and materials develop resulting in upward pressure on wages and the costs of materials. As a result, inflationary pressures begin to build. Similarly, when output is below its potential level, inflationary pressures begin to subside. This price adjustment mechanism is succinctly described by the expectations-augmented Phillips curve of Friedman (1968) and Phelps (1967):

(1) $$p = gp^{e} + k(y - y^{*})$$

where p denotes the inflation rate, p^e represents expected inflation, y is real GDP and y^* is potential GDP. The parameter $k > 0$ indicates the extent to which the inflation rate is associated with the deviation of GDP from its potential (i.e., the GDP gap) while the magnitude of g provides insight as to the degree to which inflationary momentum exists.[1] Typically, equation (1) is assumed to have constant unconditional, as well as conditional, variance. However, the inclusion of the inflation expectation term implies that inflation may indeed be time-varying (i.e., the conditional variance may not be constant). Consider what happens when the realized output gap turns out to be greater than expected. Supposing that initially inflation were equal to expected inflation, then inflation rises in the period(s) following the wider than expected output gap. Inflation will rise above its initial value before falling again to (possibly) a level below its starting value.

Depending on the size of the shock and on the magnitudes of the coefficients in equation (1), it is possible that inflation will cycle or fluctuate around its initial value over the course of several periods before returning to the initial value. This volatility of inflation is thus predictable. Moreover, it may be that inflation volatility produces more inflation (at least in the short run) as might be the case if the associated uncertainty about prices made it more difficult for agents in the economy to formulate pricing strategies. Thus, in addition to the estimation of the expectations-augmented Phillips curve allowing for time-varying variance, our empirical analysis also take into account the idea that inflation volatility may be associated with higher inflation.[2]

[1] The (short-run) Phillips curve suggests a temporary and predictable relationship between inflation and the GDP gap. Changes in expected inflation will alter this relationship, causing the Phillips curve to shift. Consequently, any observed relationship between inflation and the GDP gap will change over time as expected inflation changes. Also, the relationship between inflation and GDP will change when potential GDP grows at a different rate. In the long run, GDP will equal its potential and thus inflation will equal its expected level. No long-term relationship exists between inflation and the GDP gap and thus the long-run Phillips curve is vertical.

[2] As discussed below, we use the GARCH technique for the estimation of equation (1) allowing for time-varying variance and the GARCH-in-mean method for additionally allowing for the possibility that conditional volatility of inflation influences inflation.

In the next section, we provide a brief review of related literature and then proceed to the empirical estimation of a short-run Phillips curve that allows for time-varying volatility as well as the possibility that increases in inflation variability are associated with higher levels of inflation. In short, we find that estimates of inflation based on the Phillips curve can be made more efficient by incorporating information that is provided by the behavior of the conditional or short-run variance of the model.

2. Review of related literature

In recent years, there has been much discussion regarding the applicability of the Phillips curve Ewing and Seyfried (2000). As economic growth accelerated and unemployment fell in the late 1990s, inflation failed to increase, causing many to question the existence of any relationship between economic growth and inflation. However, Fuhrer (1995) found support for the Phillips Curve representing an extremely robust empirical relationship with little sign of instability since World War II. In a subsequent study, Fuhrer (1997) found that lagged values of inflation were more important than expected inflation in explaining the behavior of inflation.

Brayton, Roberts and Williams (1999) developed a model covering 1955-98 in which inflation depends on the unemployment rate, past inflation and price supply shocks that proved to be unstable in the 1990s. When this model was modified to include capacity utilization instead of the unemployment rate, it became more accurate for the 1990s, though not superior for the period as a whole. Introducing an error-correction mechanism involving the mark-up of prices over trend unit labor costs significantly improved the explanatory power of the model.

De Brouwer (1998) examined the role of the output gap in explaining Australian inflation. The inclusion of any of the alternative estimates of the output gap improved the fit of the equation suggesting that the movement of the gap over time helped to explain inflation. All of the measures had statistically similar estimated coefficients and performed better than growth of output in the preceding four quarters. Bolt and Van Els (2000) consider the relationship between the output gap and inflation in various EU countries as well as Japan and the US. A statistically significant relationship was found in 12 of the 13 countries studied (including the US).

A related strand of research has connected the inflation rate with its degree of volatility. In fact, several researchers have theorized that increased inflation uncertainty has a short-term effect of increasing inflation. Cukierman and Meltzer (1986) suggest that, in the absence of a commitment mechanism, central bankers engaging in discretionary policy will exhibit an inflationary bias.

Since it is more difficult to assess policymaking during periods of uncertainty, there is an increased incentive for central bankers to act opportunistically in terms of seeking to attain higher short-term economic growth. Nas and Perry (2000) found evidence in Turkey of inflation uncertainty, measured by the conditional variance of inflation, resulting in higher inflation in the short run.

Reagan and Stulz (1993) develop a theoretical model that suggests one should expect higher inflation when there is an increase in the variability of prices as a result of higher contracting costs.

Owyang (2001) develops a model in which the interaction of an unobserved shock to the Phillips curve, policymaker learning and switches in the preferences of the policymaker, result in inflation persistence, volatility clusters and correlation between the level and variance of inflation. Policymakers who are more tolerant of inflation tend to allow shocks to have a greater effect on the inflation target, causing inflation to become more variable when it is relatively high.

Thus, these papers suggest that another term might be added to the Phillips curve specification given in equation (1), namely, a term representing inflation volatility.

Clearly, there is plenty of interest in examining the major propositions set forth in the Phillips curve hypothesis. To date, however, researchers have virtually neglected the possibility of nonlinearities in the Phillips curve.[3] The present study empirically models the Phillips curve allowing for nonlinearity in the second moment. Moreover, we explicitly test whether or not increases in the conditional volatility of inflation are associated with higher levels of inflation. Previous studies have incorporated various ways of measuring excess demand or slack in the economy in their attempt to explain the behavior of inflation (for example, the unemployment rate, output gap, capacity utilization, an activity index, etc.). We have chosen to use the output gap due to its widespread use in similar models as well as its flexibility (it doesn't assume a constant NAIRU) and broad focus (unlike capacity utilization, it's not focused on the manufacturing sector).

3. Description of data

In order to estimate the Phillips curve, we use quarterly data from the U.S. from 1954Q3 to 1999Q2. The inflation rate is computed using the CPI for all urban consumers.[4] The output gap is computed using real GDP and the Federal Reserve Bank of St. Louis' measure of potential GDP.[5] All data are obtained from the Federal Reserve Bank of St. Louis economic database (FRED).

Table 1 provides descriptive statistics for the inflation rate and the output gap. The mean inflation rate over the usable sample period of 1955Q3-1999Q2 was 4.26 percent while the mean output gap was –0.33 percent.

[3] One notable exception is a recent paper by Nobay and Peel (2000). They construct a theoretical model of a nonlinear Phillips curve and consider the resulting implications for optimal monetary policy.

[4] Specifically, inflation is computed as $100\times(p_t-p_{t-4})/(p_{t-4})$.

[5] The output gap is computed as $100\times$(GDP-POT)/(POT), where GDP is real GDP and POT denotes potential GDP.

Both series exhibited excess kurtosis (i.e., "fat tails"), a characteristic often found in series with autoregressive conditional heteroskedasticity. Based on the value of the Jarque-Bera statistic, the null hypothesis of normality can be rejected in the case of inflation.

Table 1. Descriptive Statistics

	Inflation	Output Gap
Mean	4.2555	-0.3340
Median	3.3664	-0.3998
Standard Deviation	3.0516	2.5913
Kurtosis	4.3659	3.2179
Jarque-Bera	65.88 (0.0000)	3.36 (0.1860)

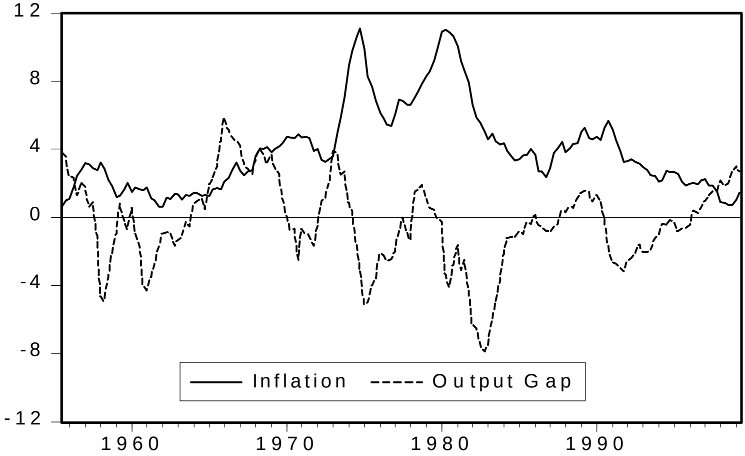
Note: The usable sample period is from 1955:3-1999:2 and contains 176 observations. Jarque-Bera is the statistic used to test the assumption of normality and the associated probability value is given in parentheses.

A plot of both series is presented in Figure 1. It appears that positive (negative) values of the output gap lead increases (decreases) in inflation as expected based on the Phillips curve hypothesis.

Additionally, it appears that large (small) changes in the inflation rate may be followed by further large (small) changes in the inflation rate.

This latter observation suggests the presence of time-varying variance, and is often referred to as volatility clustering. Certainly no definitive statements should be made regarding a Phillips curve relationship or time-varying volatility from a cursory visual examination of the series. Thus, we will proceed to a more formal examination of the inflation rate-output gap relationship that allows for a nonconstant variance.

Figure 1. Inflation and Output Gap in the U.S. 1954-1999



Note: Inflation is measured using the Consumer Price Index for all urban consumers. The output gap is defined as the percentage deviation of actual real GDP from potential GDP.

4. An empirical model of the Phillips curve

We test the hypothesis that inflation is associated with a positive GDP gap in the short run. Furthermore, we allow for the possibility that the conditional (i.e., short run) variance of inflation is not constant. The rationale of the time-varying volatility in inflation is an implication of standard Keynesian-type sticky price models with a Phillips curve price adjustment mechanism.[6] In this class of models, the short run is modeled using standard IS-LM analysis assuming that price adjustment occurs with a lag. Inclusion of inflationary expectations on the part of economic agents leads to a less-than-perfectly smooth return to equilibrium output following demand shocks. The fluctuations in output are well documented in the business cycles literature; however, these types of models also

[6] For a good example on the development of these types of models see Hall and Taylor (1997). Additionally, Romer (1996) reviews a number of variations on these types of models.

imply that the price level, and thus inflation, will also fluctuate in a predictable manner before prices establish a new equilibrium and/or in a dynamic setting, inflation returns to an equilibrium rate. It may be possible to exploit the information provided in the variability in inflation in order to improve estimates of the Phillips curve relationship between output and inflation as compared to models that ignore the time-varying nature of inflation variability.

In particular, Engle (1982) suggested that modeling both the mean and the variance of the process under investigation would improve the efficiency of the parameter estimates. The autoregressive conditional heteroskedasticity (ARCH) model of Engle (1982) was generalized by Bollerslev (1986) to the case in which the variance depends on past volatilities going back a large number of periods. The latter is referred to as the generalized autoregressive conditional heteroskedasticity (GARCH) model. The GARCH framework was extended by Engle, Lilien, and Robins (1987) to allow the mean of the series under investigation to depend on its own conditional variance, Enders (1995). The GARCH-in-mean (GARCH-M) simply augments the mean equation with the conditional standard deviation. In the context of this study, the inflation rate is allowed to respond to the short run variance and provides a way in which to test whether or not increases in inflation variability are associated with higher levels of inflation.

In order to examine the inflation-output relationship, we begin by estimating the following two equations simultaneously via the method of maximum likelihood. Note that equation (3) is simply a generally specified autoregressive moving average (ARMA) model. Equations (3) and (4) constitute the GARCH model.

(3) $$f(L)p_t = C + q(L)e_t + yG_{t-1} + l p_t^e$$

$$e_t \sim N(O, h_t^2)$$

(4) $$h_t^2 = m + \sum_{i=1}^{q} a_i e_{t-i}^2 + \sum_{j=1}^{p} b_j h_{t-j}^2$$

where y is the coefficient on the output gap variable, G; C is a constant term; and l is the coefficient on the inflationary expectations variable, p^e. In the empirical analysis it is assumed that expected inflation depends on last period's inflation rate such that $p^e = p_{t-1}$.[7] The mean equation of the inflation rate is given by (3), while (4) is the (conditional) variance equation.[8] Specifically, Var($e_t|W_{t-1}$) = h_t^2 is the conditional variance of e_t with respect to the information set W_{t-1}. Equation (4) contains a moving average component (i.e., the ARCH term) that may contain q lags and an autoregressive component (i.e., the GARCH term) that may contain p lags.

In addition to the GARCH model, the GARCH-M model is estimated to determine to what extent conditional volatility matters in explaining the inflation rate in the expectations-augmented Phillips curve. Equation (5) replaces equation (3) for the estimation of the GARCH-M model.

$$(5) \qquad f(L)p_t = C + q(L)e_t + yG_{t-1} + l p_t^e + kh_t$$
$$e_t \sim N(O, h_t^2)$$

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[7] While there are a number of possible proxies for inflationary expectations this specification is consistent with standard macroeconomic treatments such as that found in Hall and Taylor (1997). Treating expected inflation in this way allows us to obtain a consistent measure throughout the long sample period we are studying. Other forms of expected inflation were experimented with including a exponentially smoothed forecast, but based on RMSE measures, it did not perform significantly better than the simple lag specification. Additionally, we considered using the inflationary expectations measures from the Philadelphia Fed and the University of Michigan. However, neither of these measures is available for the entire sample period of our study. The former begins in 1981Q3 and the latter in 1978Q1.

[8] We computed the quasi-maximum likelihood covariances and standard errors as described in Bollerslev and Wooldridge (1992). The model is estimated under the assumption that the errors are conditionally normally distributed.

The difference between equation (3) and equation (5) is that the latter includes the conditional standard deviation as an explanatory variable. The coefficient k indicates the degree to which inflation variability and inflation are linked.

The first step in the procedure was to identify the best-fitting specification of equation (3) using standard Box-Jenkins techniques and then to test the chosen specification for the existence of autoregressive conditional heteroskedasticity. As explained by Enders (1995), the Box-Jenkins method for model selection includes an examination of the plot of the time series, the autocorrelation function and partial autocorrelation function. A principal feature of the model selection procedure is parsimony. Payne, Martin, and Potter (2000) argue that the energy shocks of 1974, 1980 and 1986 are important events that need to be controlled for when estimating the Phillips curve. Thus, we include controls (i.e., dummy variables) in the estimation of equation (3) for these supply shocks. The ARMA(0,1), or equivalently the MA(1) specification, was selected, augmented with the output gap and inflationary expectations variables.

The test described in Engle (1982, p. 1000) was used to test for the presence of ARCH effects. The mean equation exhibited evidence of autoregressive conditional heteroskedasticity.[9] Thus, estimation of the ARCH-class model is appropriate. The specification of the variance equation is determined in a similar manner as the mean equation, i.e., based on goodness-of-fit. The variance was found to follow a GARCH(1,1) process. As previously mentioned, the Phillips curve relationship may change over time. Thus, it is important to examine the stability of the coefficients in the estimating model.[10] The results of the Phillips curve model presented in this

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[9] The test statistic is distributed as a χ^2 with degrees of freedom equal to the number of restrictions. Specifically, we found first-order ARCH effects with a test statistic of 18.06 [p-value=.00]. This finding suggests that past values of volatility can be used to predict current volatility.

[10] See Ewing and Seyfried (2000) for a discussion of this topic.

paper were free of parameter instability as evidenced by CUSUM tests.

The results of estimating the GARCH and the GARCH-M models of the Phillips curve are presented in Table 2. In addition, we also report the results from ordinary least squares (OLS) regression of the Phillips curve. However, caution should be used when interpreting the OLS results, as there are significant ARCH effects. Thus, in what follows we limit our discussion primarily to the results of the GARCH and GARCH-M models.

In terms of the GARCH and the GARCH-M models, note that the estimated value of the coefficient on the moving average term in (3) and (5), respectively, is positive and significant indicating that a shock to the inflation rate is distinctly felt in two periods – the period in which it occurred and the following period.[11] For example, an unexpected increase in real output would raise the inflation rate in the current period as well as the next period. However, the effect would be transitory in nature, as the inflation rate will return to its baseline value. Furthermore, it is found that there is inflationary momentum as the coefficient on the inflationary expectations term is positive and significant (estimated coefficient value = 0.96 for the GARCH model and 0.94 for the GARCH-M model). Thus, past inflation influences current inflation and this effect is rather persistent.[12]

It is also found that an immediate past increase in the output gap measure is positively related to the current inflation rate. In

[11] The necessary and sufficient conditions for the model to be stationary were met. For a discussion of these conditions and their derivation, see Harvey (1994).

[12] Our results are in the range of those found in the literature. For example, Fuhrer's (1997) estimate of the coefficients on lagged inflation ranged from 0.75 to 0.98 while those on the output gap ranged from 0.10 to 0.18. However, the results are not directly comparable due to differences in the structure of the respective models.

particular, both the GARCH and GARCH-M models suggest that for a one percentage point increase in the deviation of real GDP from potential, the inflation rate will rise by .09 percent, all else equal. To put this in perspective, consider that the output gap in the first quarter of 1999 was approximately 3 percent and the inflation rate was about 1.7 percent.

The implication of this finding is that had the output gap been near zero, the inflation rate would have been close to 1.4. In contrast, the output gap in the first quarter of 1991 (a recession year) was about –2.7 percent and inflation was around 5.3 percent. In the absence of an output gap, the inflation rate would have been around 5.6, all else equal. These findings support the prediction of the short-run Phillips curve that the output gap is positively related to inflation.

In terms of the variance of inflation, note that both the ARCH and GARCH terms in equation (4) are significant for GARCH model. The ARCH term was also significant in the GARCH-M model while the GARCH term in the GARCH-M model was just marginally significant at only the $p=0.15$ level. The necessary condition for the mean equation to be covariance stationary, $(\alpha+\beta) < 1$, is satisfied in the case of the GARCH model (3) and the GARCH-M model (5). Q-statistics suggested that the mean equation was free of serial correlation. Correlograms of the squared standardized residuals indicated that the variance equation was correctly specified with no evidence of remaining ARCH effects.

Jarque-Bera tests indicated that the standardized residuals might not be normally distributed. However, the estimates are still consistent under quasi-maximum likelihood assumptions, see Bollerslev and Wooldridge (1992). This suggests that the volatility of the inflation rate is predictable and that it depends on how large the errors were in the past. Thus, the effect of an inflation shock, such as that arising from an unanticipated increase in aggregate consumption, would be expected to increase the volatility of the inflation rate over the short term. This finding is consistent with models of aggregate demand and supply that assume sticky or inflexible prices. In particular, this finding is consistent with the behavior of output and inflation following economic shocks, as predicted by variants of the Keynesian macroeconomic model that include an expectations-augmented Phillips curve, Romer (1996).

Table 2. Model Results

Mean equation	OLS	GARCH	GARCH-M
Constant (C)	0.2513[b] (0.13)	0.1560 (0.10)	-0.0451 (0.16)
Lagged Output Gap (G_{t-1})	0.1070[a] (0.02)	0.0888[a] (0.02)	0.0918[a] (0.02)
Inflationary Expectations (π^e)	0.9482[a] (0.02)	0.9555[a] (0.02)	0.9423[a] (0.03)
MA(1)	0.4570[a] (0.07)	0.3352[a] (0.09)	0.2978[a] (0.09)
Conditional Volatility (h)	------	------	0.5861[b] (0.28)
Variance equation			
Constant	------	0.0806[a] (0.03)	0.1030[a] (0.03)
ARCH (ε_{t-1}^2)	------	0.4787[a] (0.14)	0.4705[a] (0.15)
GARCH (h_{t-1}^2)	------	0.2665[b] (0.12)	0.1703 (0.12)
Log likelihood	-131.37	-119.25	-118.05
Q-statistic	1.43 (p=0.23)	1.37 (p=0.24)	2.73 (p=0.10)
AIC	1.58	1.48	1.47

Note: Superscripts a, b denote significance at the 1% and 5% levels, respectively. Standard errors are in parentheses. The model also included three dummy variables corresponding to the oil shocks of 1974, 1980, and 1986.

Furthermore, the results of the GARCH-M model suggest that conditional volatility is linked to higher levels of inflation as suggested by Reagan and Stulz (1993), among others. The estimated value for the coefficient k on the conditional standard deviation term equals 0.59 and is statistically significant. Thus, a one-unit change in the conditional standard deviation of inflation corresponds to more than a half point change in the inflation rate. This is an economically significant finding. For example, consider the effect of a one unit rise in the conditional standard deviation from 3 (the average standard deviation of inflation in our sample) to 4. Evaluated at the sample mean inflation rate of 4.25%, this implies that inflation would rise by 14% to 4.84%. This effect is even more pronounced during periods in which inflation is running at lower rates, as was common in the late 1990s. This finding suggests that a central bank that wants to keep inflation from rising should focus on price stability.

5. Conclusions

The results of this study are similar to those of Bolt and Ban Els (2000) and de Brower (1998). Though their models differed somewhat from the one in this study, comparisons of the estimated coefficients of the output gap and expected inflation can be made. Bolt and Van Els considered the factors affecting inflation in the US and other countries from 1971 to 1996 and found, as in this study, the appropriate lag structure for US inflation was one lag.

Similar to our results, the resulting coefficient on lagged inflation was 0.934 while the coefficient on the output gap was 0.13. de Brouwer examined inflation in Australia from 1980 to 1997, finding the estimated coefficient to range from 0.083 to 0.118, depending on which measure of the output gap was employed. Though the empirical results are similar to this study, due to differences in the models, caution should be exercised when making comparisons.

Estimates of Phillips curve type relationship, similar to those just cited, have traditionally been conducted ignoring the possibility that inflation may be time varying. However, standard Keynesian-style models suggest that output and inflation may fluctuate in a predictable manner following demand shocks. Thus, we re-examined the Phillips curve allowing for autoregressive conditional heteroskedasticity or ARCH effects.

The results support the idea that the conditional variance of inflation can be predicted. Moreover, the GARCH model of the Phillips curve provides more efficient parameter estimates than standard linear models. For comparison purposes, we also estimated equation (3), the standard short-run Phillips curve, using ordinary least squares (see Table 2). In particular, compared to the two GARCH-class models, the simple OLS model suggested a greater weight be placed on the output gap and the MA term than did the GARCH model-essentially overstating the upward price pressure from an output gap and shocks. Additionally, the OLS model suggested a lower degree of inflationary momentum.

Generally speaking, the findings presented in this paper suggest that inflation exhibits volatility persistence and more efficient, and thus more appropriate, estimates of the Phillips curve can be obtained utilizing information contained in the second moment. Perhaps more importantly, as suggested by the theoretical models developed by Reagan and Stulz (1993) and Owyang (2001), our results indicate that the inflation rate is positively related to conditional volatility. Thus, there appears to be a link between inflation and its variability and empirical models of the Phillips curve should be constructed so as to capture this relationship. Our results imply the existence of a short-run Phillips curve relationship and are consistent with many Keynesian-type models that include sticky prices.

Bibliography

Bollerslev, T.(1986). “Generalized Autoregressive Conditional Heteroskedasticity”. *Journal of Econometrics*, pp. 307-27.

Bollerslev, T. and Wooldridge, J.(1992). “Quasi-Maximum Likelihood Estimation and Inference in Dynamic Models with Time-Varying Covariances”. *Econometric Reviews*, pp. 143-72.

Bolt, W. and Van Els, P.J.A.(2000). *“Output Gap and Inflation in the EU”*. Dutch National Bank Staff Report, 44.

Brayton, F.; Roberts, J. M. and Williams, J. C.(1999). *"What's Happened to the Phillips Curve?"*. Board of Governors of the Federal Reserve System Finance and Discussion Series, 49.

Cukierman, A. and Meltzer, A.(1986). "A Theory of Ambiguity, Credibility and Inflation Under Discretion and Asymmetric Information". *Econometrica*, pp. 1099-1128.

De Brouwer, G.(1998). *"Estimating Output Gaps"*. Reserve Bank of Australia Research Discussion Paper 9809.

Dickey, D. A. and Fuller, W. A.(1981). "Likelihood Ratio Statistics for Autoregressive Time Series with a Unit Root". *Econometrica*, pp. 1057-71.

Enders, W.(1995). "Applied Econometric Time Series". 1st edition. New York, John Wiley & Sons.

Engle, R.(1982). "Autoregressive Conditional Heteroskedasticity with Estimates of the Variance of the U.K. Inflation". *Econometrica*, pp. 987-1008.

Engle, R.; Lilien, D. and Robins R.(1987). "Estimating Time Varying Risk Premia in the Tem Structure: The ARCH-M Model". *Econometrica*, pp. 391-407.

Ewing, B. T. and Seyfried, W. L.(2000). "Some Additional Thoughts about the Phillips Curve". *Social Science Quarterly*, pp. 680-82.

Friedman, M.(1968). "The Role of Monetary Policy". *American Economic Review*, pp. 1-17.
Fuhrer, J. C.(1995). "The Phillips Curve is Alive and Well". *Federal Reserve Bank of Boston New England Economic Review*.

Fuhrer, J. C.(1997). "The (un)Importance of Forward-Looking Behavior in Price Specifications". *Journal of Money, Credit and Banking*, pp. 338-350.

Hall, R. E. and Taylor, J. B.(1997). *"Macroeconomics"*. 5th edition. New York, W. W. Norton & Company.

Harvey, A. C.(1994). *"Time Series Models"*. 2nd edition. Boston, MIT Press.

King, R.G. and Watson, M. W.(1992). *"Testing Long-Run Neutrality"*. National Bureau of Economic Research, Working Paper nº 4156.

Nas, T. F. and Perry, M. J.(2000). "Inflation, Inflation Uncertainty and Monetary Policy in Turkey, 1960-98". *Contemporary Economic Policy*, pp. 170-185.

Nobay, A. R. and Peel, D. A.(2000). "Optimal Monetary Policy with a Nonlinear Phillips Curve". *Economics Letters*, pp. 159-64.

Owyang, M. T.(2001). "Persistence, Excess Volatility, and Volatility Clusters in Inflation". *Federal Reserve Bank of Saint Louis Economic Review*, pp. 1-11.

Payne, J. E., Martin, T. L.and Potter, S. N.(2000). "A New Line on the Phillips Curve: Additional Evidence on the U.S.". *Social Science Quarterly*, pp. 677-80.

Phelps, E. S.(1967). "Phillips Curve, Expectations of Inflation, and Optimal Unemployment Over Time". *Economica*, pp. 254-81.

Reagan, P. and Stulz, R.(1993). "Contracting Costs, Inflation and Relative Price Variability". *Journal of Money, Credit and Banking*, pp. 521-549.

Romer, D.(1996). *"Advanced Macroeconomics"*. New York, McGraw-Hill.