MEASURING REAL ACTIVITY IN A MODEL WITH STICKY PRICE AND STICKY INFORMATION

Mesut Murat Arslan, Baskent University

ABSTRACT

In price setting models, theory implies real marginal cost as a measure of real economic activity. But how can we measure the real marginal cost? Most of the empirical literature has used the output gap as a proxy for real marginal cost. However, measuring the output gap is problematic. Recently, unit labor cost has been used instead. In this study, a model of inflation, which is composed of sticky price and sticky information price settings, is estimated using both the output gap and unit labor cost to see which one yields more sensible and reasonable results, and so which one is a better proxy for real marginal cost. ***JEL classifications:*** E10; E31; E37

INTRODUCTION

The New Keynesian Phillips curve (NKPC) model has been commonly used in the short-run inflation dynamics literature. In this model, each firm adjusts its price with some probability in each period independent of waiting time. But this model has been criticized for producing implausible results regarding inflation dynamics.[1] Therefore, alternative models have been developed. Such as Mankiw and Reis (2002) proposed the sticky information Phillips curve. In this model, a fraction of firms get complete information about the economy in each period randomly and independent of waiting time, and set their prices according to this new information, while the remaining firms set their prices according to old information. Also, there is a new approach in theoretical modeling that leads to a hybrid model, which combines the sticky price and sticky information models in a single price setting model.[2]

Price setting models (Phillips Curves) relate inflation to some measures of real economic activity, which is usually represented by unobservable real marginal costs as implied by theory. Real marginal cost should be measured to be able to estimate such models. However, there have been a considerably disagreement about the proxy for real marginal cost. Most of the empirical literature has used the output gap as an appropriate proxy for real marginal cost. However, there are difficulties in measuring and obtaining the true output gap since, although output is observable, the potential output, which is needed to be able to calculate the output gap, is unobservable. Therefore, using the output gap in inflation models involves some difficulties and problems in explaining inflation dynamics and data. Because of those difficulties, some recent literature has started to use the unit labor cost as another proxy for real marginal cost.

Therefore, it is important to know which variable to be used to measure real marginal cost in estimations of price setting models. Although theory implies real marginal costs to represent real economic activity in New Keynesian macroeconomics framework, there is no consensus on how to proxy this unobservable marginal cost.

So, the main contribution of this study is to obtain an additional finding on the proxy for real marginal cost by using a hybrid model of inflation. This study estimates a hybrid model that combines the sticky price and sticky information models. This model is based on Arslan (2010) and called the SP/SI Phillips curve that nests the standard sticky price and sticky information models as special cases. This model is estimated by using the output gap and unit labor cost as proxies for real marginal cost to see which variable is more appropriate to measure real activity and so real marginal cost in such a framework.

The SP/SI Phillips curve is estimated by a nonlinear instrumental variables (GMM) method and a full information VAR-based maximum likelihood estimation (MLE) method with the U.S. data. There are two important structural parameters that can be used to compare the output gap and unit labor cost as alternative proxies. The first parameter of interest is the fraction of firms whose prices remain fixed whether they are sticky price or sticky information type firms; it is interpreted as a measure of the degree of price stickiness in the economy. The other parameter of interest is the fraction of sticky price type firms and interpreted as a measure of relative importance of the price setting models. Therefore, this study will investigate the effects of the chosen variable for real marginal cost on the estimated values of those parameters.

The estimation results show that the structural parameters of the SP/SI Phillips curve are estimated much more reasonably when unit labor cost is used rather than the output gap. When unit labor cost is used the price stickiness parameter is estimated to be 0.88 by GMM and 0.90 by MLE, these values imply an average period for fixed prices around 8 and 10 quarters.[3] These values are not very unrealistic and far from generally accepted levels. Also, some statistically significant fractions of both sticky price and sticky information firms are estimated, although the sticky price firms form the majority. But, when those estimations are performed by using the output gap, price stickiness parameter is estimated to be very high around 0.95, which implies unrealistically high 20 periods for fixed prices. Also, the fraction of the sticky price might be estimated higher than one. These results are robust to alternative sub-samples.

THE SP/SI PHILIPS CURVE

In a New Keynesian framework firms produce in a monopolistically competitive market. In the sticky price model, a fraction 1-θ of firms adjust their prices in each period according to the expectations about future economic conditions, and the remaining fraction θ of firms keep their prices unchanged. When a sticky price firm has the opportunity to change its price, it sets the price equal to the average of the expected desired prices until the next adjustment opportunity. This adjustment price is given as:

$$q_t = (1-\beta\theta)\sum_{k=0}^{\infty}(\beta\theta)^k E_t\{mc_{t+k}^n\} \qquad (1)$$

Here, q_t is optimal adjustment price, β is discount factor, and mc^n is nominal marginal cost. Therefore, optimal price is set by taking the expected future path of nominal marginal costs into account. The aggregate price index p_t^{sp} is given by a convex combination of unchanged price and optimal adjustment price as:

$$p_t^{sp} = \theta p_{t-1} + (1-\theta) q_t \tag{2}$$

In the sticky information model, information about macroeconomic conditions spreads slowly throughout the population; although prices are set every period, information collecting and processing take time. When a firm changes its price at period *t*, the new price that applies beginning in period *t* is chosen on the basis of the last information it has at period *t-k*; that is, according to the state of the economy as of period *t-k*. In each period, a fraction 1-θ of firms get complete information about the economy and set their prices according to this new information and the remaining fraction θ of firms set their prices according to old information. The aggregate price level p_t^{si} is the average of all prices:

$$p_t^{si} = (1-\theta)\sum_{k=0}^{\infty} \theta^k E_{t-k}\{mc_t^n\} \tag{3}$$

Therefore, the sticky information firms set their prices by taking all of the past expectations of current nominal marginal cost into account.

The SP/SI Phillips curve is derived by combining these two price adjustment models. Both sticky price and sticky information type firms are assumed to be coexist. A fraction ω of firms are sticky price type, the remaining fraction 1-ω of firms are sticky information type. During each period, a randomly selected fraction 1-θ of firms are chosen to change their prices. In such a framework, the aggregate price index would be weighted average of aggregate price levels for the sticky information and sticky price type firms as:

$$p_t = (1-\omega) p_t^{si} + \omega p_t^{sp} \tag{4}$$

The SP/SI Phillips curve can be obtained from this expression as:

$$\pi_t = C_t + \lambda_1 mc_t + \lambda_2 E_t \pi_{t+1} + \lambda_3 E_t mc_{t+1} \tag{5}$$

where $\lambda_1 = \dfrac{(1-\omega)+(1-\theta)\omega(1-\beta\theta)}{\theta\omega}$; $\lambda_2 = \beta$; $\lambda_3 = -\dfrac{\beta(1-\omega)}{\omega}$

Here C_t is an expression in model parameters and the past expectational errors for nominal marginal cost, and π_t is the current period inflation rate. In this equation, all coefficients depend on the structural parameters β, θ and ω of the model. This is the SP/SI Phillips curve, which is an encompassing model and nests both the sticky price and sticky information Phillips curves.[4]

MEASUREMENT OF REAL MARGINAL COST

The SP/SI Phillips curve is derived above in terms of real marginal cost, and the more familiar output gap does not appear in it. Theoretical models of price setting usually imply real marginal cost as a measure of real economic activity as can be seen in the optimal price setting equations above. However, most of the empirical literature has used the output gap as the measure of real economic activity by assuming it to be

an appropriate proxy for real marginal cost. This arises from the fact that, under certain conditions, real marginal cost and the output gap are proportional.[5] The output gap is usually taken as the log deviation of output from its potential level and usually computed by linear or quadratic detrending the log GDP. So, it is difficult to measure the output gap because it relies on unobservable potential output. Thus, the output gap used in empirical studies may not represent the true output gap. Therefore, estimates of price setting models with the output gap have some difficulties in fitting the data and explaining the inflation dynamics. Because of those problems with the output gap, unit labor cost has been started to be used as another proxy for real marginal cost.[6]

Those difficulties and problems may be explained by two approaches. The first approach claims that real marginal cost is not closely related to the output gap, and so the price setting models should use another variable for real marginal cost. In this approach, some researchers claim that the empirical difficulties of the NKPC model arise from using the output gap, which is not a good proxy for real marginal cost. Because of difficulties with using the output gap, some recent literature has used the unit labor cost as another proxy for real marginal cost. Such as Lown and Rich (1997) says that the ability of traditional Phillips curves to explain the data is weakened by mismeasurement of the true output gap. They showed using nominal unit labor costs in Phillips curve greatly improves its fit to data. Gali and Gertler (1999) showed that NKPC can explain the inflation dynamics considerably when real unit labor cost is used instead of the output gap to measure real marginal cost. The success with unit labor costs may be attributable to the sluggish behavior of unit labor costs that help the models explain inflation dynamics. Gali, Gertler and López-Salido (2001) obtained some results that imply a weak relationship between real marginal cost and the output gap. Some recent literature that has used marginal cost as the driving force for inflation dynamics and measured it by labor costs, among many others, are Sbordone (2002, 2005), and Batini et al. (2005).

The second approach claims that marginal cost and the output gap are closely related, but the output gap should be measured in a consistent way with theory. The poor performance of price setting models may not be an evidence against the output gap; rather, it may show difficulties in measuring the output gap. Under this interpretation, real marginal cost has a closer relationship to the true output gap than do traditional measures represent. Real shocks produce fluctuations in the natural level of output, which is therefore not well approximated by smoothing it out and obtaining trend. A recent study of Neiss and Nelson (2005) obtained a considerable improvement in the empirical performance of output-gap based Phillips curves by using theory-consistent estimates of the output gap. They found little support for the notion that labor costs explain inflation dynamics better than the output gap, and so concluded that modeling of labor market rigidities is not a high priority in analyzing inflation. Some studies among others that point out the link between the output gap and real marginal cost are Gali (2000), Neiss and Nelson (2001), and Woodford (2001).

ESTIMATION OF THE SP/SI PHILLIPS CURVE

The SP/SI Phillips curve in (5) can be put into the following empirical form by adding a disturbance term u_t to the model:

$$\pi_t - C_t = \lambda_1 mc_t + \lambda_2 E_t \pi_{t+1} + \lambda_3 E_t mc_{t+1} + u_t \qquad (6)$$

This study estimates the above model by the GMM and a VAR-based MLE methods.[7] Since the main parameters of interest in this study are θ, which measures the degree of price stickiness, and ω, which is the fraction of sticky price type firms, the other structural parameter β, which is discount factor, is calibrated to be 0.99 in the estimations. I use quarterly U.S. data over the period 1960:1 to 2008:4. The data set includes the non-farm business sector unit labor cost and output, change in the GDP deflator, commodity price inflation, wage inflation, and the federal fund rate.

Under rational expectations, all information dated t-1 and earlier is uncorrelated with the error term u_t in (6). Therefore, the orthogonality condition for the SP/SI Phillips curve in GMM can be

$$E_t\left\{(\theta\omega(\pi_t - C_t) - [(1-\omega) + (1-\theta)\omega(1-\beta\theta)]mc_t - \beta\theta\omega\pi_{t+1} + \theta\beta(1-\omega)mc_{t+1})Z_{t-1}\right\} = 0 \quad (7)$$

where $\mathbf{Z}_{t-1}$ is a vector of instrumental variables, which are dated t-1 and earlier. It forms the basis for estimating the model by GMM. The structural parameters are estimated by non-linear instrumental variables estimator. The instrument set includes six lags of inflation, the output gap, unit labor cost, commodity price inflation, wage inflation, and interest rate.

The SP/SI Phillips curve is also estimated by using the full-information MLE method. For the purpose of this estimation, an unconditional VAR model is estimated. The structural equation given by the SP/SI Phillips curve is combined with the estimated equations from the VAR model. Under rational expectation, those equations would be consistent. Then, the resultant dynamic system is solved by using the Anderson and Moore's (1985) AIM algorithm, and likelihood is formed based on the one-step-ahead forecast errors.[8]

ESTIMATION RESULTS

In this study one parameter of interest is θ, which represents the fraction of firms whose prices remain unchanged each period. So, it measures the degree of price stickiness in the economy. The other parameter of interest is ω and is defined as the fraction of the sticky price firms, and so measures the degree of the standard sticky pricing approach in price setting.

Estimation results of the SP/SI Phillips curve by both methods are given in Table 1.[9] When unit labor cost is used as proxy for real marginal cost, the parameter θ is estimated to be 0.88 and 0.9 respectively for the whole period, which implies eight to ten quarters for the average duration of fixed prices. Although this value is a little higher than the generally accepted levels, it is not very unrealistic.[10] However, when the output gap is used as the measure of real marginal cost, θ is estimated to be around 0.95 by both estimation methods.[11] This value of θ implies 20 quarters for the average duration of fixed prices. This value represents an unreasonable and unrealistic value for this parameter. The other parameter ω is estimated significantly to be around 0.94 when unit labor cost is used. This implies that most of the firms are sticky price type firms. The parameter ω is estimated to be 0.98 and 1.01 that is higher than one when the output gap is used.

In the SP/SI Phillips curve, the reduced form coefficients of real marginal cost λ_1 and λ_3 represent the effects of real activity on inflation. When the output gap is used as a proxy for marginal cost, those coefficients are much smaller than the ones estimated with unit labor cost in both methods. Also, the coefficient λ_1 is negative and

insignificant in MLE method with the output gap.[12] So the effects of real activity on prices are not very clear when the output gap is used as proxy.

TABLE 1
ESTIMATION OF THE SP/SI PHILLIPS CURVE

Estimation Method	Real Activity	θ	ω	λ_1	λ_2	λ_3
GMM	ULC	0.888	0.943	0.082	0.99	-0.059
		(0.015)	(0.016)	(0.014)	0.000)	(0.017)
	OUTPUT GAP	0.951	0.969	0.036	0.99	-0.032
		(0.021)	(0.011)	(0.010)	0.000)	(0.011)
MLE	ULC	0.902	0.980	0.034	0.99	-0.020
		(0.053)	(0.009)	(0.010)	0.000)	(0.009)
	OUTPUT GAP	0.954	1.011	-0.008	0.99	-0.010
		(0.111)	(0.013)	(0.012)	0.000)	(0.013)

Notes: θ: Measure of the price stickiness ($\theta = 0$: fully flexible price; $\theta = 1$: fixed prices)
ω: Fraction of sticky price firms ($\omega = 0$: pure SI; $\omega = 1$: pure SP)
λ_1: Coefficient of real marginal cost in the SP/SI Phillips curve,
λ_2: Coefficient of expected next period inflation in the SP/SI Phillips curve
λ_3: Coefficient of expected next period real marginal cost in the SP/SI Phillips curve.

Those results are robust to estimation with different sub-samples as seen in Table 2. The whole sample is divided into two sub-samples as the periods 1960:1-1980:4 and 1981:1-2008:4. The data shows that the first period can be characterized by having high inflation and the second period by having low inflation. So the parameter θ is expected to be lower in the first period than in the second period. This expectation is satisfied in all cases except the estimation by MLE with the output gap. Table 2 shows that both parameters θ and ω are usually estimated higher with the output gap in both GMM and MLE methods, which implies longer and so unrealistic price stickiness, and more sticky price firms with the output gap. The estimations with the sub-samples illustrate that the problems with the output gap are more obvious in the MLE method when the parameters are estimated as greater than one.

Although the estimates of the structural parameters change with the samples, the main conclusion does not change much. Therefore, the results for the sub-samples also confirm that the estimations with unit labor cost are much more sensible and realistic than the estimations with the output gap, and the output gap may not be a good measure of marginal cost and real activity. So the unit labor cost would be preferred as proxy for real marginal cost in estimations of inflation dynamics.

TABLE 2
ESTIMATION OF THE SP/SI PHILLIPS CURVE BY GMM AND MLE IN SUB-PERIODS

Estimation Method	Real Activity	Period	θ	ω	λ_1	λ_2	λ_3
GMM	ULC	1960:1-1980:4	0.847	0.882	0.187	0.99	-0.133
			(0.008)	(0.008)	(0.006)	(0.000)	(0.010)
		1981:1-2008:4	0.867	0.974	0.053	0.99	-0.026
			(0.009)	(0.008)	(0.007)	(0.000)	(0.009)
	OUTPUT GAP	1960:1-1980:4	0.870	0.972	0.053	0.99	-0.028
			(0.018)	(0.008)	(0.008)	(0.000)	(0.008)
		1981:1-2008:4	0.895	0.920	0.011	0.99	-0.086
			(0.013)	(0.007)	(0.005)	(0.000)	(0.009)
MLE	ULC	1960:1-1980:4	0.672	0.826	0.476	0.99	-0.209
			(0.060)	(0.093)	(0.006)	(0.000)	(0.134)
		1981:1-2008:4	0.913	1.031	-0.024	0.99	0.029
			(0.116)	(0.024)	(0.028)	(0.000)	(0.022)
	OUTPUT GAP	1960:1-1980:4	1.056	1.004	-0.001	0.99	0.004
			(0.017)	(0.000)	(0.001)	(0.000)	(0.000)
		1981:1-2008:4	0.926	0.978	0.030	0.99	-0.022
			(0.052)	(0.030)	(0.038)	(0.000)	(0.031)

Notes : See notes to Table 1.

CONCLUSION

In this study, a hybrid model of sticky price and sticky information price settings, which is called the SP/SI Phillips curve, is estimated using both the output gap and unit labor cost as alternative proxies for real marginal cost that shows the real economic activity in an economy. This structural model of inflation is estimated by a nonlinear instrumental variables (GMM) method and a full information MLE method by using U.S. data for the period 1960-2008. Estimations show that more reasonable and sensible results are obtained when unit labor cost is used as a proxy for real marginal cost rather than the output gap. Therefore, unit labor cost may be preferred over the output gap as a measure of real activity in the economy when inflation is modeled and estimated by the SP/SI Phillips curve. This result is also robust to alternative sub-samples. So this study provides a new empirical evidence that favors the unit labor cost in such a hybrid framework for modeling inflation. The result of this study also justifies the results for the sticky price NKPC obtained by some studies mentioned in the text.

REFERENCES

Anderson, Gary and George Moore. 1985. “A Linear Algebraic Procedure for Solving Linear Perfect Foresight Models.” *Economic Letters* 27: 247-252.

Arslan, M.Murat. 2006. “Derivation and Estimation of a Phillips Curve with Sticky Price and Sticky Information Models.” Working Paper, University of Houston.

Arslan, M.Murat. 2008. "Dynamics of the Sticky Information and Sticky Price Models in a New Keynesian DSGE Framework." *Economic Modelling* 25: 1276-1294.

Arslan, M.Murat. 2009. "Measures of Marginal Cost in the Estimation of a Hybrid Model of Sticky Price and Sticky Information Price Settings" *The Journal of American Academy of Business,* Cambridge 14: 308-314.

Arslan, M.Murat. 2010. "Relative Importance of Sticky Prices and Sticky Information in Price Setting" *Economic Modelling* 27: 1124-1135.

Batinia, Nicoletta, Brian Jackson and Stephen Nickell. 2005. "An open-economy new Keynesian Phillips curve for the U.K." *Journal of Monetary Economics* 52: 1061–1071.

Fuhrer, Jeff and George Moore. 1995. "Inflation Persistence." *Quarterly Journal of Economics* 440: 127-159.

Gali, Jordi. 2000. "New Perspectives on Monetary Policy, Inflation, and the Business Cycle." Manuscript, CREI, Universitat Pompeu Fabra.

Gali, Jordi and Mark Gertler. 1999. "Inflation Dynamics: A Structural Econometric Analysis." *Journal of Monetary Economics* 44: 195-222.

Gali, Jordi, Mark Gertler and J. David Lopez-Salido. 2001. "European Inflation Dynamics." *European Economic Review* 45: 1237-1270.

Kiley, Michael T. 2007."A Quantitative Comparison of Sticky Price and Sticky Information Models of Price Setting." *Journal of Money, Credit, and Banking* 39: 102-125.

Korenok, Oleg and Norman R. Swanson. 2007. "How Sticky Is Sticky Enough? A Distributional and Impulse Response Analysis of New Keynesian DSGE Models." *Journal of Money, Credit and Banking* 39: 1481-1508.

Lown, Cara S. and Robert W. Rich. 1997. "Is There An Inflation Puzzle." *Federal Reserve Bank of New York Quarterly Review*, 51-69.

Mankiw, N.Gregory and Ricardo Reis. 2002. "Sticky Information versus Sticky Prices: A Proposal to Replace the New Keynesian Phillips Curve." *Quarterly Journal of Economics* 117: 1295-1328.

Neiss, Katharine S., and Edward Nelson. 2001. "The Real Interest Rate Gap as an Inflation Indicator." Bank of England Working Paper No. 130.

Neiss, Katharine S., and Edward Nelson. 2005. "Inflation Dynamics, Marginal Cost, and the Output Gap: Evidence from Three Countries." *Journal of Money, Credit, and Banking* 37: 1019-1045

Rotemberg, Julio J., and Michael Woodford. 1997. "An Optimization Based Econometric Framework for the Evaluation of Monetary Policy." *NBER Macroeconomics Annual* 12: 297-346.

Sbordone, Argia M. 2002. "Prices and Unit Labor Costs: A New Test of Price Stickiness." *Journal of Monetary Economics* 49: 265-292.

Woodford, Michael. 2001. "The Taylor Rule and Optimal Monetary Policy." *American Economic Review (Papers and Proceedings)* 91: 232–237.

ENDNOTES

1. See Arslan (2008) for a review of such critics.
2. There have been such studies recently, some of those include Korenok and Swanson (2006), Kiley (2007), Arslan (2010).
3. If the value of price stickiness paramater is x, the number of quarters in which prices are fixed is calculated as $1/(1-x)$.

4. For the derivations and details of this model see Arslan (2006).
5. Rotemberg and Woodford (1997) show that when capital is fixed, marginal cost and output are approximately proportional.
6. One can easily obtain unit labor cost as a measure of real marginal cost by simply assuming a Cobb-Douglas technology. Firms' cost minimization problem yields that marginal cost is proportional to the income share of labor (unit labor cost).
7. This study is an extension of Arslan (2009), which tried to identify the most suitable proxy for real marginal cost by using only the MLE method.
8. The estimation method is similar to the approach used by Fuhrer and Moore (1995). The AIM algorithm transforms the structural equations of the model into the state-space representation. Then, by using the stability and initial conditions, it excludes potential solutions which never converge to the steady state.
9. In GMM estimation, the standard errors are calculated by using a 12-lag Newey-West estimate of the covariance matrix. Although not reported in the table, the Hansen's J-statistic is calculated for overidentifying restriction, that shows the instruments used in GMM are valid.
10. Gali and Gertler (1999) found this duration as five to six quarters, while Sbordone (2002) found as nine to 14 months.
11. The results shown here are obtained when the output gap is taken as the quadratically detrended log GDP. However, the results are barely affected when linear detrending is used.
12. The coefficient of real marginal cost appears to be negative in the NKPC when the output gap is used, as opposed by the theory, as shown in Gali and Gerler (1999).