Inflation Dynamics and Velocity of Money

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Abstract

There have been large changes in the velocity of money which could be a potential source of inflation variability. This paper extends a Calvo style sticky price model to examine the role of the velocity of money in inflation dynamics from both a theoretical and empirical perspective. When money is introduced via transactions cost, the resultant Phillips curve becomes a function of velocity as well as an output gap and a forward looking inflation terms, a feature for which we provide empirical support. More specifically, we adopt the GMM methodology to estimate the velocity augmented Phillips curve using the US data between 1951 and 2005. We observe that historical inflation dynamics is consistent with the velocity-augmented forward looking Phillips curve.

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1 Introduction

Over the post war period, there have been large changes in the velocity of money. The introduction of several cash-saving technologies, such as nationwide credit and debit cards, NOW, sweep accounts has contributed to increased variability in the velocity of money which in turn can be a source of inflation variability. This paper extends a New Keynesian framework to investigate the impact of exogenous changes in the velocity of money on inflation.

Our model follows Kim-Subramanian (2006), where real money balances serve to reduce transactions costs. These costs act like a distortionary consumption tax fluctuating endogenously with the velocity of money. An increase in the velocity of money, for example, results in an increase in the transactions costs. This in turn results in an increase in the effective price of consumption thereby altering the labor leisure choice. The presence of these costs therefore affects real marginal costs faced by the firms. We show that the resultant aggregate supply curve or the New Keynesian Phillips curve now becomes a function of the velocity of money. Fluctuations in the velocity of money thereby directly result in fluctuations in the aggregate supply curve in the economy. We then proceed to provide empirical support on the relevance of the velocity component in the estimation of the forward looking Phillips curve. Specifically, we employ the GMM methodology to investigate the significance of velocity term in the Phillips curve. Various specifications and instrument sets are used to verify the reliability of the parameter estimates for the US economy during 1959:1Q to 2005.

The rest of the paper proceeds as follows. Section 2 develops the model. Section 3 examines it under flexible and sticky prices respectively. Section 4 estimates the Phillips curve and tests for the presence of a velocity component. Then we conclude.
2 Model

The economy consists of a representative household that supplies labor, purchases goods for consumption, holds money and bonds. Firms, hire labor, produce and sell differentiated products in monopolistically competitive goods markets.

The representative household derives utility from a composite consumption good $C_t$, and leisure, $1 - N_t$, where $N_t$ is the time devoted to market employment and maximizes

$$E_t \sum_{i=1}^{\infty} \beta^t \left[ \frac{C_{t+i}^{1-\sigma}}{1-\sigma} - \chi \frac{N_{t+i}^{1+\eta}}{1+\eta} \right],$$

where the composite consumption good is defined as a weighted sum of differentiated good $c_j$

$$C_t = \left[ \int_0^1 c_{jt}^{\frac{\theta-1}{\theta}} dj \right]^{\frac{\theta}{\theta-1}} \theta > 1. \tag{2}$$

The parameter $\theta$ measures the constant price elasticity of demand for the individual goods. The household first minimizes the cost of buying $C_t$, $\int_0^1 p_{jt} c_{jt} dj$ given (2) to obtain

$$c_{jt} = \left( \frac{p_{jt}}{P_t} \right)^{-\theta} C_t,$$

where $P_t$ is the aggregated price index for consumption and given as

$$P_t = \left[ \int_0^1 p_{jt}^{-\theta} dj \right]^{\frac{1}{1-\theta}}. \tag{3}$$

Agents hold money to reduce transactions cost. The transactions cost $S_t$ is defined as

$$S_t = e^{\epsilon_t} C_t k_0 v_t^{(k_1-1)} \quad k_0 > 0, \quad k_1 > 1 \tag{4}$$

where $v_t$ is the velocity of money and is defined as $\frac{PC}{M}$ and $\epsilon_t$ is a shock to the transaction technology.
We can now write the budget constraint of the household as

\[ C_t + \frac{M_t}{P_t} + B_t + e^{\epsilon_t} C_t k_0 v_t^{(k_1-1)} = \left( \frac{W_t}{P_t} \right) N_t + \frac{M_{t-1}}{P_t} \]
\[ + (1 + i_{t-1}) \frac{B_{t-1}}{P_t} + \Pi_t + T_t, \]

(5)

where \((1 + i_{t-1})\) is the gross nominal interest rate paid on bonds, \(\Pi_t\) is the profits received from firms, \(T_t\) are lump-sum transfers from the government.

Next, the agents maximize (1) subject to (5). The first order conditions are given as:

\[ C_t^{-\sigma} = \lambda_t \left[ 1 + e^{\epsilon_t} k_1 k_0 v_t^{k_1-1} \right] \]

(6)

\[ C_t^{-\sigma} = \beta(1 + i_t) E_t \left( \frac{P_t}{P_{t+1}} \right) \left[ \frac{1 + e^{\epsilon_t} k_1 k_0 v_t^{k_1-1}}{1 + e^{\epsilon_{t+1}} k_1 k_0 v_{t+1}^{k_1-1}} \right] C_{t+1}^{-\sigma} \]

(7)

\[ v_t^{k_1} = \frac{1}{e^{\epsilon_t} k_0 (k_1 - 1)} \left( \frac{i_t}{1 + i_t} \right) \]

(8)

\[ \chi \frac{N_t^\psi}{C_t^{-\sigma}} \left[ 1 + e^{\epsilon_t} k_1 k_0 v_t^{k_1-1} \right] = \frac{W_t}{P_t} \]

(9)

An increase in \(v_t\) or \(\epsilon_t\) will tend to increase the effective price of consumption and hence decrease consumption. (7) is the standard Euler equation. (8) implicitly defines the households money demand function. (8) implies that a rise in \(\epsilon\) will lead to a decrease in the velocity of money, while a rise in the interest rate will lead to an increase in the velocity of money. It follows from (8) that shocks to \(\epsilon_t\) can be interpreted as shocks to the velocity of money. (9) shows that fluctuations in the velocity of money will distort the consumption/leisure margin. Given real wage rate, a higher \(\epsilon_t\), \(v_t\) will tend to make people consume less and work less.

Defining \(\hat{X}_t\) as the percentage deviation of variable \(X_t\) from its steady state value \(\bar{X}\), we now express the variables in (7), (8), and (9) in terms of their percentage deviations from steady state. These equations help us to attain some of the model’s implications:
\[
\sigma(\hat{E}_t \hat{C}_{t+1} - \hat{C}_t) = (\hat{R}_t - \hat{E}_t \hat{\pi}_{t+1}) + \frac{V_0 (1 - k_1)}{1 + V_0} (\hat{E}_t \hat{\upsilon}_{t+1} - \hat{\upsilon}_t) - \frac{V_0}{1 + V_0} (\hat{E}_t \hat{\epsilon}_{t+1} - \hat{\epsilon}_t),
\]
(10)

\[
\hat{W}_t - \hat{P}_t = \sigma \hat{C}_t + \eta \hat{N}_t + \frac{V_0}{1 + V_0} \hat{\epsilon}_t + \frac{V_0 (k_1 - 1)}{1 + V_0} \hat{\upsilon}_t,
\]
(11)

\[
\hat{\upsilon}_t = \frac{\hat{R}_t}{k_1 (\hat{R} - 1)} - \frac{1}{k_1} \hat{\epsilon}_t,
\]
(12)

where \((1 + i_t)\) is \(R_t\) and \(V_0\) is \((1 + \bar{\epsilon}) k_0 k_1 \bar{\epsilon}^{k_1 - 1}\).

Firms employ labor to produce output using a constant returns to scale technology. The production function of the firm is given by

\[
c_{jt} = A_t N_{jt}
\]
(13)

where \(c_{jt}\) is the output produced by firm \(j\), \(N_{jt}\) is labor hired by firm \(j\) and \(A_t\) represents current technology in the economy.

Following the Calvo-Yun setup, firms adjust their price infrequently. Each period, the firms that adjust their price are randomly selected, and a fraction \((1 - \omega)\) of all firms adjust while the remaining \(\omega\) fraction does not adjust. By solving the profit maximization problem of firms as in Kim and Subramanian (2006) or Sbordone (2002), one can obtain an inflation-adjustment equation of the form

\[
\hat{\pi}_t = \beta \hat{E}_t \hat{\pi}_{t+1} + \kappa \hat{m}_c t
\]
(14)

where \(\hat{\pi}_t\) is the deviation of the inflation around the steady-state of \(\pi\) and \(\hat{m}_c t\) is the percentage deviation of the real marginal cost \((m_c t = W_t / P_t A_t)\) around its steady state value of \(\frac{\theta}{\pi-1}\) (denoted as \(\mu^{-1}\)), where

\[
\kappa = \frac{(1 - \omega)(1 - \omega \beta)}{\omega}
\]
(15)

Now, equilibrium conditions are specified. Following Vegh (2002), assume that the government gives back to the households as lump-sum transfers the proceeds from transaction costs. This implies that the transactions
cost is a private cost for the consumer and not a social cost. Formally, the government is assumed to provide shopping services to the consumer and the proceeds from such an activity are then transferred back to the consumer in a lump-sum way. In addition the government also returns in a lump-sum manner the proceeds from money creation. The budget constraint of the government is given by

$$T_t = \frac{M_t - M_{t-1}}{P_t} + e^\epsilon C_t V \left( \frac{M_t}{P_t C_t} \right)$$

Thus, the model abstracts from wealth effects arising due to transactions costs or seigniorage. This allows us to focus on the distortionary effects of money.

Since this is a representative agent model, the aggregate net private lending must be zero:

$$B_t = 0$$

Substituting (16), and (17) into the households budget constraint, we get the goods market equilibrium

$$C_t = Y_t$$

### 3 Flexible and sticky price equilibria

Flexible price implies that all firms charge the same price and real marginal cost is constant, such that $MC_t = \frac{1}{\mu}$, where $\mu$ is the constant markup charged by firms under flexible prices. This would imply that

$$\frac{W_t}{P_t} = \frac{A_t}{\mu}$$

From (13), real wage must be equal to the marginal rate of substitution between leisure and consumption. This implies that

$$\chi \frac{N_t^q}{C_t^\sigma} [1 + e^\epsilon k_1 k_0 v_t^{k_1-1}] = \frac{W_t}{P_t} = \frac{A_t}{\mu}$$
(20), and goods market clearing condition $Y_t^F = C_t$, and $Y_t^F = A_t N_t$, the flexible price level output $Y_t^F$ in a linearized form is

$$
\hat{Y}_t^F = \frac{1 + \eta}{\sigma + \eta} \hat{A}_t - \frac{V_0}{(1 + V_0)(\sigma + \eta)} \{(k_1 - 1) \hat{v}_t^F + \hat{e}_t\} \tag{21}
$$

Now let us turn our attention to the sticky price setup. Following Calvo-Yun setup, firms cannot adjust prices every period and therefore must take into account expected future marginal cost as well as current marginal cost whenever it has an opportunity to adjust price. We can rewrite the marginal cost of the firm in terms of percentage deviations as,

$$
\hat{mc}_t = \hat{W}_t - \hat{P}_t - \hat{A}_t \tag{22}
$$

Substituting for $\hat{W}_t - \hat{P}_t$ from (11), (22) becomes

$$
\hat{W}_t - \hat{P}_t - \hat{A}_t = (\sigma + \eta) \hat{Y}_t - (1 + \eta) \hat{A}_t + \frac{V_0}{(1 + V_0)} \hat{e}_t + \frac{V_0 (k_1 - 1)}{(1 + V_0)} \hat{v}_t \tag{23}
$$

We can use (21) to rewrite $\hat{mc}_t$ as

$$
\hat{mc}_t = (\hat{Y}_t - \hat{Y}_t^F) (\sigma + \eta) - \frac{V_0 (k_1 - 1)}{(1 + V_0)} (\hat{v}_t^F - \hat{v}_t)
$$

The Phillips curve given by (14), can be rewritten as

$$
\hat{\pi}_t = \beta E_t \hat{\pi}_{t+1} + \kappa (\sigma + \eta) (\hat{Y}_t - \hat{Y}_t^F) + \frac{\kappa V_0 (k_1 - 1)}{(1 + V_0)} (\hat{v}_t - \hat{v}_t^F) \tag{24}
$$

(24) shows that the aggregate supply curve is not just a function of the output gap, but also a function of velocity. This feature distinguishes our analysis from other studies. (24) says that changes in velocity will affect inflation. The model thus provides a clean interpretation of the mechanism through which changes in velocity affect inflation.
4 Velocity augmented Phillips curve estimation

4.1 Econometric Specifications

We estimate the aggregate supply function (24) with a velocity gap, the output gap and the forward-looking inflation terms. The standard New Keynesian Phillips curve without velocity terms has been estimated by Gali and Gertler (1999), Gali, Gertler, and Lopez-Salido (2001). The objective is to estimate the deep parameters \( \omega, \beta, \) and \( V_0/(1 + V_0) \) conditional on \( \sigma, \eta, \) and \( k_1. \) We rewrite (24) in terms of realized variables to obtain

\[
\hat{\pi}_t = \beta \hat{\pi}_{t+1} + \kappa (\sigma + \eta)(\hat{Y}_t - \hat{Y}_t^F) + \frac{\kappa V_0 (k_1 - 1)}{(1 + V_0)} (\hat{\nu}_t - \hat{\nu}_t^F) + \xi_t, 
\]

where \( \xi_t = -\beta (\hat{\pi}_{t+1} - E_t \hat{\pi}_{t+1}) \) is the forecast error. We identify the parameters of interest via GMM. It allows an efficient estimation when there exists heteroskedasticity of unknown form.\(^1\) Now we generate a moment condition given by

\[
0 = E_t \left[ \hat{\pi}_t - \beta \hat{\pi}_{t+1} - \gamma_1 (\hat{Y}_t - \hat{Y}_t^F) - \gamma_2 (\hat{\nu}_t - \hat{\nu}_t^F) \right],
\]

where \( \gamma_1 = \kappa (\sigma + \eta) \), and \( \gamma_2 = \frac{\kappa V_0 (k_1 - 1)}{(1 + V_0)} \). Denoting \( Z_t \) as the set of instrument variables orthogonal to the forecasting error, the moment conditions are

\[
0 = E_t \left[ \{ \hat{\pi}_t - \beta \hat{\pi}_{t+1} - \gamma_1 (\hat{Y}_t - \hat{Y}_t^F) - \gamma_2 (\hat{\nu}_t - \hat{\nu}_t^F) \} \cdot Z_t \right].
\]

Alternatively, using the definition of \( \kappa \) in (15) and (25), we can directly identify the parameters via

\[
0 = E_t \left[ \begin{array}{c}
\omega \hat{\pi}_t - \omega \beta \hat{\pi}_{t+1} \\
-(1 - \omega)(1 - \omega \beta)\{(\sigma + \eta)(\hat{Y}_t - \hat{Y}_t^F) \\
+ \frac{V_0 (k_1 - 1)}{(1 + V_0)} (\hat{\nu}_t - \hat{\nu}_t^F) \}
\end{array} \right] \cdot Z_t,
\]

\(^1\)We checked with Breuch-Pagan test, White test, and others to find out that heteroskedasticity exists in a standard regression analysis of our model.
or

\[ 0 = E_t \left\{ \frac{\hat{n}_t - \beta \hat{n}_{t+1}}{\omega + \frac{V_0 (k_1 - 1)}{(1 + V_0)} (\hat{v}_t - \hat{v}_t^F)} \right\} \cdot Z_t \].

We label (26), (27), (28) as specification 1, 2, and 3 respectively. All the specifications require knowledge on \( \sigma, \eta, k_1 \) to estimate \( \omega, \beta, \) and \( V_0/(1 + V_0) \). Thus, we could check stability of estimates, while computing the parameters with alternative equations. Additionally, specifications 2 and 3 will provide another robustness check on the estimates because non-linear GMM is sensitive to the way moment conditions are normalized, especially in small samples.

Another important issue related to small sample properties is the weak instrument problem. GMM is a consistent estimator, but not an unbiased estimator, and it is known that increasing the number of weak instruments could increase bias of estimates while lower their variances. Following Bound, Jaeger, and Baker (1995), we used F-test of the joint significance of \( Z_t \) instruments in the first-stage regression. However, when multiple endogenous variables exist, F-test may not be sufficient and a parsimonious selection of instrument variables is often recommended (Staiger and Stock (1997)). Since there exists no clear way of selecting good instruments in case of non-linear GMM estimation, we present the estimates with three instrument sets found in the literature.

Our benchmark instrument vector includes three lags of GDP deflator inflation, four lags of real GDP gap and real unit labor cost, one lag of three-month treasury bill rate and M1 velocity gap. The real GDP gap and the velocity gap terms are computed using the Hodrick-Prescott Filter. In case of output gap, we also used output gap measure available from the Bureau of Economic Analysis, and virtually little changes occur. We label the above set as instrument set 1. The instrument set 2, which is smaller, consists of two lags of GDP deflator inflation, one lag of real GDP gap, one lag of 3-month treasury bill rate, two lags of real unit labor cost, and one lag of M1 velocity gap. The instrument set 3, which is larger, has four lags of
PPI inflation, unemployment rate, and long-term interest rates measured by 10-year constant maturity treasury yields. These variables are in addition to those present in instrument set 1.

We used the quarterly data for the US economy over 1959:1Q to 2005:1Q. All the series are from the St. Louis Federal Reserves Web page (FRED). Parameters and weighting matrices are iterated until convergence of parameters for estimations, following Hansen (1982). This recursive procedure has the same asymptotic properties as the two-stage estimation, yet better performs in small samples, because it is less sensitive to the choice of initial weighting matrix.

4.2 Empirical results

Table 1 displays the estimates of the parameters with the specification 1 for three sets of instruments. The estimates of $\beta$ are 0.95 to 0.994, consistent with the discount rate commonly used in the literature. The parameters $\gamma_1$ and $\gamma_2$ have the right signs and have small standard errors. The estimated value of $\gamma_1 = \kappa(\sigma + \eta)$ is around 0.23. Estimates of $\gamma_2 = \kappa(k_1 - 1)V_0/(1 + V_0)$ are in the range of 0.02 to 0.03. Inserting $\sigma = 1.5$ and $\eta = 1$, which are standard in the literature, the implied value of $\kappa$ is 0.092. Using the definition of $\kappa$ in (15) and an estimate of $\beta$ (0.99), we compute the fraction of firms not adjusting the price, $\omega$, as 0.742. This estimate of $\omega$ is consistent with the values obtained by Gali and Gertler (1999) and Ravenna and Walsh (2003). J-tests confirm that we cannot reject the overidentifying restrictions against model misspecification with a caution that J-test is of low power.

Table 2 presents the estimates for all three specifications with three instrument sets. We estimate $\beta$, $\omega$, $V_0/(1 + V_0)$ given $\sigma$, $\eta$, $k_1$. Specification 1 reports imputed value after linear GMM estimation. Specifications 2 and 3 report estimates based on non-linear settings. We found $\omega$ to be unstable across alternative specifications. Interestingly, the first specification result gives some clue about the instability. By construction, $\omega$ can have multiple solutions in the equation, and different setting favors one solution over the
other. We report the possible parameter values for the specification 1 and it is easily observed that the specification 2 leans toward the smaller value, while the specification 3 prefers the larger \( \omega \). However, all of the estimates on \( \omega \) together with \( \beta \) to compute \( \kappa(\sigma + \eta) \) show significant, positive signs consistent with the theoretical prediction.

The estimates of \( V_0/(1 + V_0) \) are mostly significant though, somewhat volatile depending on instrument set and specification.

In conclusion the empirical estimates support our hypothesis of a velocity component in the Phillips curve.

5 Conclusion

Changes in the velocity of money can lead to inflation variability. In a model where money serves to reduce transaction costs we investigate the role of velocity of money in explaining inflation dynamics. Transactions cost in our model acts like a distortionary consumption tax which varies endogenously with velocity. The presence of this tax alters the labor-leisure trade-off and affects the marginal cost of the firm. The resultant Phillips curve therefore becomes a function of the velocity of money. GMM estimations of this Phillips equation suggest that the US economy is consistent with the model.

References


Table 1. GMM estimation result: Specification 1 (US; Quarterly)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Instrument Set 1</th>
<th>Instrument Set 2</th>
<th>Instrument Set 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.99 (0.015)</td>
<td>0.994 (0.016)</td>
<td>0.95 (0.095)</td>
</tr>
<tr>
<td>$\gamma_1$</td>
<td>0.23 (0.097)</td>
<td>0.235 (0.040)</td>
<td>0.24 (0.046)</td>
</tr>
<tr>
<td>$\gamma_2$</td>
<td>0.02 (0.006)</td>
<td>0.019 (0.007)</td>
<td>0.03 (0.005)</td>
</tr>
<tr>
<td>$J$-statistics</td>
<td>12.6 [0.254]</td>
<td>3.88 [0.422]</td>
<td>20.543 [0.943]</td>
</tr>
</tbody>
</table>

Note) Iterative GMM estimates of the Phillips curve (25) with the moment conditions.

$$0 = E_t \left[ \left\{ \hat{\pi}_t - \beta \hat{\pi}_{t+1} - \gamma_1 (\hat{Y}_t - \hat{Y}_t^F) - \gamma_2 (\hat{v}_t - \hat{v}_t^F) \right\} \cdot Z_t \right].$$

Standard errors are reported in brackets and computed with Newey-West correction. p-values for the $J$-statistics are reported.
<table>
<thead>
<tr>
<th>Parameters</th>
<th>$\beta$</th>
<th>$\omega$</th>
<th>$\left( \frac{V_0}{1+V_0} \right)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specification 1:</td>
<td>(1) 0.990 (0.015)</td>
<td>${0.742, 1.361}$</td>
<td>0.1552</td>
</tr>
<tr>
<td></td>
<td>(2) 0.994 (0.016)</td>
<td>${0.738, 1.362}$</td>
<td>0.1443</td>
</tr>
<tr>
<td></td>
<td>(3) 0.950 (0.095)</td>
<td>${0.749, 1.404}$</td>
<td>0.2232</td>
</tr>
<tr>
<td>Specification 2:</td>
<td>(1) 1.013 (0.047)</td>
<td>0.450 (0.045)</td>
<td>0.03 (0.002)</td>
</tr>
<tr>
<td></td>
<td>(2) 0.994 (0.057)</td>
<td>0.709 (0.012)</td>
<td>0.08 (0.031)</td>
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<tr>
<td></td>
<td>(3) 0.938 (0.012)</td>
<td>0.581 (0.012)</td>
<td>0.04 (0.007)</td>
</tr>
<tr>
<td>Specification 3:</td>
<td>(1) 0.975 (0.016)</td>
<td>1.587 (0.119)</td>
<td>0.028 (0.009)</td>
</tr>
<tr>
<td></td>
<td>(2) 0.994 (0.016)</td>
<td>1.362 (0.131)</td>
<td>0.113 (0.094)</td>
</tr>
<tr>
<td></td>
<td>(3) 0.949 (0.010)</td>
<td>1.642 (0.051)</td>
<td>0.110 (0.102)</td>
</tr>
</tbody>
</table>

Table 2. GMM estimation result (US; Quarterly)

Note) (1), (2), (3) refer to intrument set 1, 2, and 3 respectively.
Parameters for the Specification 1, except $\beta$, were computed using the restriction $\gamma_1 = \kappa(\sigma + \eta)$, $\gamma_2 = \kappa(k_1 - 1) \left( \frac{V_0}{1+V_0} \right)$, and $\kappa = (1 - \omega)(1 - \beta \omega)/\omega$. In so doing, $k_1 = 2.4$, $\sigma = 1.5$, $\eta = 1$ were used. Estimates for $\omega$ report two values in $\{\}$ due to the fact that the restriction is quadratic in $\omega$, i.e. $\kappa = (1 - \omega)(1 - \beta \omega)/\omega$.
Specification 2 and 3 also use $k_1 = 2.4$, $\sigma = 1.5$, $\eta = 1$ to identify the parameters directly. Standard errors are reported in brackets and computed with Newey-West correction. Hansen’s J-test were performed and for all of the cases we could not reject over-identifying restrictions, and J-statistics are not reported.