The Velocity of M1 in the 1980s: Evidence from a Multivariate Time Series Model*

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I. Introduction

The velocity of $M1$ declined in the 1980s after an upward trend over the previous twenty years. This apparent break in the process generating velocity was an important consideration in the Federal Reserve's deemphasis of $M1$ as an intermediate target in 1982. Discussion of the behavior of velocity has focused upon whether the process generating velocity underwent a shift, perhaps due to the financial innovation and deregulation in the 1980s, or whether the behavior of velocity merely reflects the underlying variability in its determinants. Tatom [34], Darby et al. [7], Stone and Thornton [33], and Rasche [30] provide summaries of this debate. No consensus has emerged on whether the process generating the velocity of $M1$ shifted after 1982.

The aim of the present paper is to analyze the behavior of velocity before and after 1982. The approach taken here is quite different from the traditional method of analyzing velocity which relies upon single-equation estimates of velocity or money demand functions. A vector autoregressive (VAR) model that contains the income velocity of $M1$ and its key economic determinants (income, interest rates, inflation, and money growth variability) is estimated using quarterly data for the period 1961:1–1981:4. The adequacy of this model is evaluated by calculating variance decompositions. A Monte Carlo simulation technique similar to that described in Doan and Litterman [8] is used to compute standard errors for the variance decompositions. This allows a judgement as to the significance of the response of velocity to its economic determinants. The effects of these variables on velocity for the period 1982:1–1988:4, the period of velocity's unusual behavior, are estimated through computation of historical decompositions. Formal stability tests are also performed to determine if there was a change in the process generating velocity after 1982.

The VAR modeling approach is chosen because it is well-suited to an examination of the channels through which economic variables influence velocity. As noted by Fischer [14] and Genberg, Salemi, and Swoboda [19], few restrictions are placed on the way in which the system's variables interact.[1] The VAR model treats all variables as jointly determined and thus makes no

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[1] The use of VARs has been examined critically by Cooley and LeRoy [6] and Leamer [24]. However, since the purpose of this study is not the estimation of structural effects but is instead the estimation of the response of velocity to shocks to its determinants, the VAR procedure is appropriate for this procedure.

a priori assumptions about the exogeneity of the determinants of velocity as is often done in single equation studies.

In section II of the paper, the specification of the model is discussed, and the empirical results are presented in section III. Section IV provides a summary and conclusions.

II. Model Specification

The VAR model is based upon the following specification of the velocity function:

$$V1 = V(y, i_S, i_L, i_E, \pi^E, MVOL) \tag{1}$$

where

$V1$ = income velocity of $M1$,
y = real income,
i_S = short-term interest rate,
i_L = long-term interest rate,
i_E = yield on equities,
π^E = expected inflation rate, and
$MVOL$ = money growth volatility.

The velocity function is based upon the specification of Friedman [15], although there are some differences.[2] In Friedman's specification, the scale variable is wealth or permanent income. In practice, permanent income is often measured as a distributed lag on actual income, and the equation for velocity in the VAR model does contain a distributed lag on income. For this reason, actual real income is used in the VAR model.

The yields on three types of financial assets are employed in the velocity function. The yields on *both* short-term and long-term bonds are included since, in principle, the entire term structure of interest rates on bonds affects money demand and hence velocity (Friedman [16]; Heller and Khan [22]).[3] Although changes in the yields on short- and long-term bonds are correlated, this correlation is less than perfect. Since equities and money are also substitutes, the yield on equities is also included.[4] Furthermore, since money and physical assets are substitutes, a measure of the yield on physical assets—the expected inflation rate—is also included in the specification.

The final variable employed is money growth volatility. A theoretical justification for inclusion of this variable is based upon the arguments of Mascaro and Meltzer [26] and Evans [13]. Increased money growth volatility is thought to raise the variability of interest rates and hence the risk of holding bonds. The increased riskiness of holding bonds raises money demand and velocity falls. A similar argument has been made by Friedman [17] who contended that the increased money growth volatility in the period after October, 1979 when the Federal Reserve switched to a

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[2] Equation (13) in Friedman specifies velocity as a function of the yield on bonds, the yield on equities, the rate of inflation, permanent income, the ratio of non-human to human wealth, and a tastes and preferences variable. No attempt is made here to construct a measure of the ratio of non-human to human wealth because of the difficulty of such a task. An additional difference from Friedman's specification is the inclusion of yields on both short-term and long-term bonds.

[3] Heller and Khan [22] estimate a quadratic function of the term structure and employ the estimates of the parameters of the term structure equation as arguments in the money demand function. This approach does not appear to be feasible in the type of model estimated here.

[4] Hamburger [21] has recently estimated a money demand function that contains a short-term interest rate, a long-term interest rate, and a measure of the yield on equities.

nonborrowed reserves operating target raised the level of uncertainty which in turn raised money demand (and hence reduced velocity).[5] Hall and Noble [20] found evidence that money growth volatility Granger-causes velocity.[6] Evidence of other macro effects of money growth volatility is found by Mascaro and Meltzer [26], Belongia [1], Tatom [35; 36], and McMillin [27].

Quarterly data for the period 1959:1–1988:4 are employed in this study. Data from 1959:1–1960:4 are used as presample data, and the estimation of the system is carried out over 1961:1–1981:4.[7] The model variables are: *V1*, the income velocity of $M1$ measured as nominal GNP divided by $M1$; y, real GNP; *RCP*, the six-month commercial paper rate; *AAA*, Moody's AAA corporate bond rate; *DPR*, the dividend-price ratio for Standard and Poor's Composite Common Stock Price Index; *INF*, the rate of change in the GNP deflator; and *MVOL*, an eight-quarter moving standard deviation of the growth in $M1$.[8] Following Tatom [34], the actual rate of inflation rather than a measure of the (unobserved) expected rate of inflation is employed. It should be noted that the expected rate of inflation is often measured as a distributed lag on its own past values and on lagged values of other variables that might be useful in forecasting inflation. The inflation equation in the VAR can be regarded as consistent with this approach since it contains lagged values of inflation and the other variables in the model. All data are from Citibase, and, except for *RCP*, *AAA*, and *DPR*, are seasonally adjusted at the source. Although the use of seasonally unadjusted data are often preferable for this type of study, the desire to use real GNP

[5] Further effects of increased money growth volatility have been discussed in detail in Tatom [35; 36] and have been summarized in McMillin [27].

[6] Hall and Noble's results have recently been questioned by Mehra [28] and Brocato and Smith [3]. Mehra found that first differencing the volatility measure (as is indicated by tests for a first order unit root) led to the conclusion that money growth volatility does not Granger-cause velocity. As a result, particular attention is paid to this issue in the text. Brocato and Smith found, using monthly rather than quarterly data, that money growth volatility does not Granger-cause velocity in the November 1979–September 1985 period.

[7] The eighth lag for 1961:1 is 1959:1. The data published by the Federal Reserve for the current definition of $M1$ begin in 1959:1. In order to obtain a growth rate measure for $M1$ for 1959:1 and a value for *MVOL* for 1959:1, data for the current definition of $M1$ for the period 1953:1–1958:4 were generated in the following manner. The current definition of $M1$ was regressed on old $M1$ (currency + demand deposits) for the period in which data on the two measures overlap. The estimated coefficients from this regression in conjunction with the values of old $M1$ for 1953:1–1958:4 were used to generate values for the current definition of $M1$ for 1953:1–1958:4.

[8] The variability of money growth, *MVOL*, is measured as an eight-quarter moving standard deviation of the quarterly growth in $M1$. Specifically,

$$MVOL_t = [(1/8) \sum_{i=1}^{8} (DLM1_{t-i} - \overline{DLM1_t})^2]^{1/2} \tag{1}$$

where $MVOL_t$ = the standard deviation of the change in the log of $M1$, $DLM1_{t-i}$ = the change in the log of $M1$ in quarter $t - i$, and $\overline{DLM1_t}$ = the mean of the change in the log of $M1$ over the previous eight quarters $(\overline{DLM1_t} = (1/8)\Sigma_{i=1}^{8} DLM1_{t-i})$. This is similar to measures used in previous studies, and it captures much of the intrayear variation in the growth of $M1$.

The sensitivity of the results to the measurement of *MVOL* was examined by utilizing 4 and 12 quarter moving standard deviations of the quarterly growth in $M1$ and by employing a simple ARCH measure of the standard deviation of $M1$ growth. The ARCH measure was constructed by first specifying an autoregressive equation for $M1$ growth over 1955:2–1988:4. The AIC criterion was used to specify the lag length for this equation, and the optimal lag length was estimated to be 5 quarters. The presence of an ARCH effect was then tested by regressing the squared residuals from this equation on a constant and one lagged value of the squared residuals. Both coefficients in this equation were positive and significant. A χ^2 statistic with one degree of freedom equal to the number of observations times the R^2 was computed as 9.40. This is significant at the 1% level and confirms the existence of an ARCH effect. The square roots of the fitted values of the second equation were used as an alternative measure of money growth volatility.

Since, for each of the alternative measures of *MVOL* and for all orderings considered, the variance decomposition results for the effects of *MVOL* on *V1* were within two standard deviations of those for the 8 quarter moving standard deviation, only results for the 8 quarter measure are reported.

Table I. Unit Root and Cointegration Tests

Variable	Estimated Test Statistic
A. Unit Root Tests[a]	
LV1	−1.52
Ly	−1.87
MVOL	−1.28
INF	−3.37
RCP	−2.86
AAA	−1.65
DPR	−1.77
B. Cointegration Tests[b]	
LV1	−1.88
Ly	−2.15
MVOL	−2.25
INF	−2.40
RCP	−2.56
AAA	−2.61
DPR	−2.94

a. *LV1* and *Ly* are the log levels of *V1* and real GNP, respectively. The critical value of the test statistic at the 5% level is ≈ −3.45 and is taken from Table 8.5.2 of Fuller [18]. Eight lags are employed in the tests.

b. Eight lags are employed in the tests. As discussed in the text, the critical value at the 5% level is −4.15.

and the GNP deflator which are not available in seasonally unadjusted form necessitated the use of seasonally adjusted data. Furthermore, most prior studies of velocity have employed seasonally adjusted data.

It is necessary to render the data stationary prior to specification and estimation of the VAR. Dickey-Fuller tests for first order unit roots of the type described by Nelson and Plosser [29] were performed in order to determine the appropriate transformation of the variables. These tests, which employed 8 lags, were performed over the 1961:1–1981:4 period, and the estimated test statistics are reported in Table I,A.[9] The tests indicate first order unit roots for the log levels of *V1* and *y*, and the levels of *MVOL*, *INF*, *RCP*, *AAA*, and *DPR*. Thus, like Mehra [28], a first order unit root was found for the money growth volatility measure. This suggests that first differences of the logs of *V1* and *y* and the first differences of the levels of the other variables should be used in specifying and estimating the models.

Engle and Granger [11] have emphasized the importance of testing for cointegration among the variables included in a VAR model. These variables are said to be cointegrated if each, taken separately, is nonstationary but some linear combination of the variables is stationary. Engle and Granger point out that a VAR estimated with only differenced data will be misspecified if the variables are cointegrated and the cointegrating relationships are ignored. Furthermore, the variance decompositions and historical decompositions may be unreliable if cointegration among the variables exists and is ignored since some methods of computing the moving average representa-

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[9] The equations used in the Dickey-Fuller tests regressed the level of a variable on a constant, a linear time trend, one lagged value of the level of the variable, and 8 lagged values of the first difference of the level of the variable. For *V1* and *y*, the log level was used. The hypothesis that the coefficient on the lagged value of the dependent variable was equal to 1 was tested by subtracting 1 from the estimated coefficient on the lagged dependent variable and dividing by the estimated standard error of this coefficient. The result was compared with the critical value from Table 8.5.2 of Fuller [18].

tion of the VAR are unstable in the presence of cointegration. The Dickey-Fuller tests described earlier indicated that the nondifferenced variables are nonstationary, and the procedure described in Engle and Yoo [12] is used to test for cointegration. In this procedure, a cointegrating regression is first estimated. In this regression, the contemporaneous value of one of the model variables is regressed on a constant and the contemporaneous values of the remaining variables in the model. The residuals from this equation are then subjected to a Dickey-Fuller test. Failure to reject the null hypothesis of a unit root is evidence against cointegration since a unit root is indicative that the linear combination of the variables is nonstationary. There are as many cointegrating regressions as there are variables in the system.

The cointegrating regressions were estimated over 1961:1–1981:4, and the second stage Dickey-Fuller tests, which employed 8 lags, were estimated over 1963:2–1981:4. The results of these tests are reported in Table IB. The system estimated here is a 7 variable system. Engle and Yoo [12] provide critical values for systems up to 5 variables and sample sizes of 50, 100, and 200. The estimated test statistics in Table I are compared to critical values for a 5 variable system with 50 observations. This provides a conservative test since the absolute values of the critical values rise with the number of variables in the system and since the sample size for the second stage Dickey-Fuller tests is 75. The critical value at the 5% level for a 5 variable system with 50 observations is −4.15. Based upon a comparison of the estimated test statistics with this critical value, there appears to be no evidence of cointegration in the system. Thus, the system is estimated with the differenced variables.

Following Lutkepohl [25], Akaike's AIC criterion is used to determine the lag length of the VAR model. The lag length chosen is the one that minimizes

$$AIC(k) = \ln \det \sum_{k} + (2d^2k)/T, \tag{2}$$

$k = 1, \ldots, m$ where d = the number of variables in the system, m = maximum lag length considered (set to 8 quarters[10]), det Σ_k = determinant of Σ_k, and Σ_k = estimated residual variance-covariance matrix for lag k. The AIC criterion, which chooses longer lags than the BIC criterion, was chosen to avoid bias introduced by underspecification of the lag length. The AIC criterion suggested a lag of 8 quarters for the estimation period 1961:1–1981:4.[11] Q statistics indicated the absence of any serial correlation in the residuals of the model.

III. Empirical Results

The appropriateness of the VAR model of velocity is evaluated by computing variance decompositions (VDC's) and historical decompositions (HD's). VDC's and HD's are based upon the moving average representation of the VAR model. VDC's show the proportion of forecast error variance for each variable that is attributable to its own innovations and to shocks to the other system variables. Forecast errors for a particular variable (say, *V1*) at a particular time horizon

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[10] Given the relatively large number of variables in the model (7), it was felt that considering a maximum lag of greater than 8 quarters would undesirably reduce the degrees of freedom for estimation.

[11] Since the optimal lag coincided with the maximum lag considered, the VAR was estimated with 9 lags over the periods 1961:1–1981:4, and the variance decompositions were computed. With a few exceptions, the VDC results are within one standard deviation of those for the 8 lag model. The major differences in the 9 lag model are the effects of *AAA* on *V1* are somewhat greater and the own shocks to *V1* explain somewhat less than in the 8 lag model.

will be due to errors in forecasting *V1* in previous periods as well as to errors in forecasting the other variables in the system. The VDC for *V1* will thus indicate the percentage of the forecast error variance of *V1* accounted for by shocks to *V1*, *MVOL*, and the other variables in the system.[12] Since the VDC's and HD's are based upon the moving average representation of the system, they capture both direct and indirect effects. Details of the derivation of the moving average representation and the computation of the VDCs are provided in Judge et al. [23].

The importance of providing estimates of the precision with which the VDCs are computed has recently been stressed by Runkle [31] who pointed out that reporting VDCs without estimating the associated standard errors is analogous to reporting regression coefficients without t-statistics. Consequently, as noted earlier, a Monte Carlo integration technique similar to that described in Doan and Litterman [8] was used to generate estimates of the standard errors of the VDC's. Five hundred draws were employed in the Monte Carlo procedure.

HDs are used to assess the impact of the right-hand side variables of equation (1) on *V1* over the 1982:1–1988:4 period of unusual velocity behavior. As noted by Burbidge and Harrison [4], the HD assigns credit for the difference between what can be called the base projection for a series and the actual series to the shocks to the system's variables. The extent to which a series that adds the shocks to a particular variable(s) to the base projection is closer to the actual series than is the base projection alone is a measure of the importance of that variable or that set of variables.

Like VDC's, HD's are based upon the moving average representation of the VAR. The moving average representation of the VAR can be written as:

$$\mathbf{x}_t = \sum_{i=0}^{\infty} \mathbf{M}_i \mathbf{u}_{t-i} \tag{3}$$

where $\mathbf{x}_t$ = column vector of the variables in the system, $\mathbf{u}_{t-i}$ = column vector of shocks to the elements of x in period $t - i$, and $\mathbf{M}_i$ = matrix of impulse response weights conformable to the dimensions of $\mathbf{x}$ and $\mathbf{u}$. Consider a base period which runs from observation 1 to observation T. The value of x in periods subsequent to T can be written as:

$$\mathbf{x}_{T+j} = \sum_{i=j}^{\infty} \mathbf{M}_i \mathbf{u}_{T+j-i} + \sum_{i=0}^{j-1} \mathbf{M}_i \mathbf{u}_{T+j-i} \tag{4}$$

where $\sum_{i=j}^{\infty} \mathbf{M}_i \mathbf{u}_{T+j-i}$ = base projection or forecast of $\mathbf{x}_{T+j}$ based only upon information available at time T, and $\sum_{i=0}^{j-1} \mathbf{M}_i \mathbf{u}_{T+j-i}$ = the part of $\mathbf{x}$ accounted for by shocks since T. The elements of the second term are used to determine the extent to which addition of the shocks to a particular variable(s) to the base projection generates a series that is closer to the actual series ($\mathbf{x}_{T+j}$) than is the base projection alone (first term).

Since no contemporaneous terms enter the equations of the VAR, any contemporaneous relations among the variables are reflected in the correlation of residuals across equations. In calculating the VDC's and HD's, the variables are ordered in the manner specified below, and the variance-covariance matrix is orthogonalized by the Choleski decomposition. Because of the cross-equation residual correlation, when a variable higher in the order changes, variables lower in the order are assumed to change. The extent of the change depends upon the covariance of the variables higher in the order with those lower in the order. The orderings considered

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[12] Sims [32] has argued that the strength of Granger-causal relations can be measured by VDC's. If, for example, *MVOL* explains only a small portion of the forecast error variance of *V1*, this could be interpreted as a weak Granger-causal relation.

are: (1) $MVOL, y, INF, RCP, AAA, DPR, V1$; (2) $MVOL, RCP, AAA, DPR, y, INF, V1$; (3) $MVOL, y, INF, AAA, RCP, DPR, V1$; and (4) $y, INF, RCP, AAA, DPR, MVOL, V1$.

The following considerations led to the selection of these orderings. Placement of $V1$ last allows shocks to each of the other variables to contemporaneously alter $V1$. This is consistent with the literature on estimating money demand and velocity functions in which current values of the explanatory variables affect money demand or velocity. In ordering (1), the yield variables—RCP, AAA, and DPR—follow $MVOL$, y, and INF. This is based upon efficient markets considerations and allows shocks to $MVOL$, y, and INF to contemporaneously alter these financial market variables. Term structure considerations led to placement of the short-term rate prior to the long-term rate. Placement of $MVOL$ prior to y and INF allows this variable to contemporaneously alter y and INF as well as the financial variables. This is consistent with the work of Mascaro and Meltzer [26], Belongia [1], and Tatom [36] who find contemporaneous effects of $MVOL$ on interest rates, nominal GNP, or prices. In ordering (2), the yield measures are placed before y and INF which allows shocks to these variables to contemporaneously affect y and INF. Ordering (3) is similar to ordering (1) but reverses the positions of AAA and RCP, thereby allowing contemporaneous shocks to AAA to affect RCP. Ordering (4) places $MVOL$ after the other non-$V1$ variables and thus allows shocks to these variables to contemporaneously alter $MVOL$.[13]

The VDC's are presented in Table II. Since the focus of the paper is on velocity, only the proportions of the forecast error variation in $V1$ explained by itself and the other variables are presented. The estimated standard errors are presented in parentheses beside the VDC results. The estimates of the proportion of forecast error variation explained by each variable are judged to be "significant" if the estimate is at least twice the estimated standard error. VDC's at horizons of 4, 8, 12, and 20 quarters are presented in order to convey a sense of the dynamics of the system. Since the results for orderings (2)–(4) were, with very few exceptions, within one standard deviation of those for ordering (1), only the results for ordering (1) are presented. We observe that each of the variables suggested by theory has significant effects on $V1$. The magnitude of the effects differs across variables, however. RCP, AAA, y, and $MVOL$ (at longer horizons) have effects of similar magnitude while the effects of INF and DPR are somewhat weaker.[14] Together, RCP, AAA, and DPR explain at least a third of the variation in $V1$, thereby indicating the importance of financial market yields on the behavior of velocity over the 1961:1–1981:4 period.

The VDC's indicate that the economic determinants of velocity were important in explaining the behavior of velocity over 1961:1–1981:4. It is also of interest to see if these determinants were of similar importance in the period (1982:1–1988:4) in which velocity apparently deviated from its prior behavior. Since the small number of observations in this period precludes the estimation of a VAR and computation of VDC's using data from just this period, the effect of the economic

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[13] Bernanke [2] has recently suggested an alternative to the Choleski decomposition as a way of handling the contemporaneous correlation among shocks. He suggests specifying and estimating a structural model for these contemporaneous shocks. The residuals from such a procedure would be purged of contemporaneous correlation and could be thought of as primitive shocks, providing, of course, that an appropriate structural model is specified. This procedure is not followed here because of the nature of the VAR estimated. Since the only variables included are those suggested by money demand theory, it would be difficult to specify an acceptable structural model since many variables (like supply shocks or policy variables) are omitted from the VAR and since a variable not typically found in structural models, velocity, is included in the VAR. However, since theoretical considerations are important in selecting the orderings used here, this approach can be viewed as being in the spirit of Bernanke.

[14] Furthermore, the results for $MVOL$ are not due solely to the inclusion of the 1979:4–1981:4 period (when $MVOL$ was very high due to a change in Federal Reserve operating procedures). When the model is estimated over the period 1961:1–1979:3, the results for $MVOL$ are within one standard deviation of those in Table II.

Table II. Variance Decompositions for *V1*[a]

Explained by Innovations In	Horizon (Quarters)	Relative Variation in *V1* 1961:1–1981:4
MVOL	4	9.0 (4.8)
	8	9.8 (5.0)
	12	15.5 (5.9)*
	20	12.2 (5.8)*
y	4	18.8 (5.5)*
	8	16.3 (4.6)*
	12	15.2 (4.5)*
	20	16.5 (5.2)*
INF	4	3.6 (2.5)
	8	6.4 (3.1)*
	12	7.1 (3.2)*
	20	7.2 (3.4)*
RCP	4	18.2 (6.4)*
	8	16.3 (5.4)*
	12	15.4 (5.3)*
	20	12.7 (5.6)*
AAA	4	10.2 (4.4)*
	8	10.5 (3.8)*
	12	12.3 (4.3)*
	20	17.6 (5.5)*
DPR	4	4.3 (3.4)
	8	7.3 (3.6)*
	12	6.8 (3.1)*
	20	8.5 (3.4)*
V1	4	35.9 (6.2)*
	8	33.5 (5.8)*
	12	27.7 (5.5)*
	20	25.2 (5.5)*

a. The * superscript indicates that the VDC value is at least 2 standard deviations larger than the estimated standard error which is in parentheses.

determinants on velocity is assessed by computing HD's for 1982:1–1988:4. As discussed earlier, HD's provide an indication of the impact of the individual variables on the behavior of velocity in a particular time period.

The results of the HD for ordering 1 are presented in Figures 1–3 and are summarized in Table III. The results for the other orderings were again quite similar and, as a consequence, are not reported. Plotted in Figures 1–3 are the actual velocity series (solid line), the base projection (large dashed line), and the base projection plus the contribution of a particular variable (small dashed line). For *MVOL*, we note that over 1982–mid-1983 the base projection (BP) plus *MVOL* line lies closer to the actual series than does the BP line. After this, however, addition of *MVOL* shocks to the BP does not generate a series that is consistently closer to the actual series than is the BP alone. Addition of shocks to *y* to the BP creates a series that is typically closer to the actual series than is the BP alone from late 1982–1988. The *BP* + *INF* line, for the most part, lies closer to the actual series in 1982 and from early 1984–1988 than does the BP line. Addition of shocks to the yield variables to the BP creates series that are generally closer to the actual

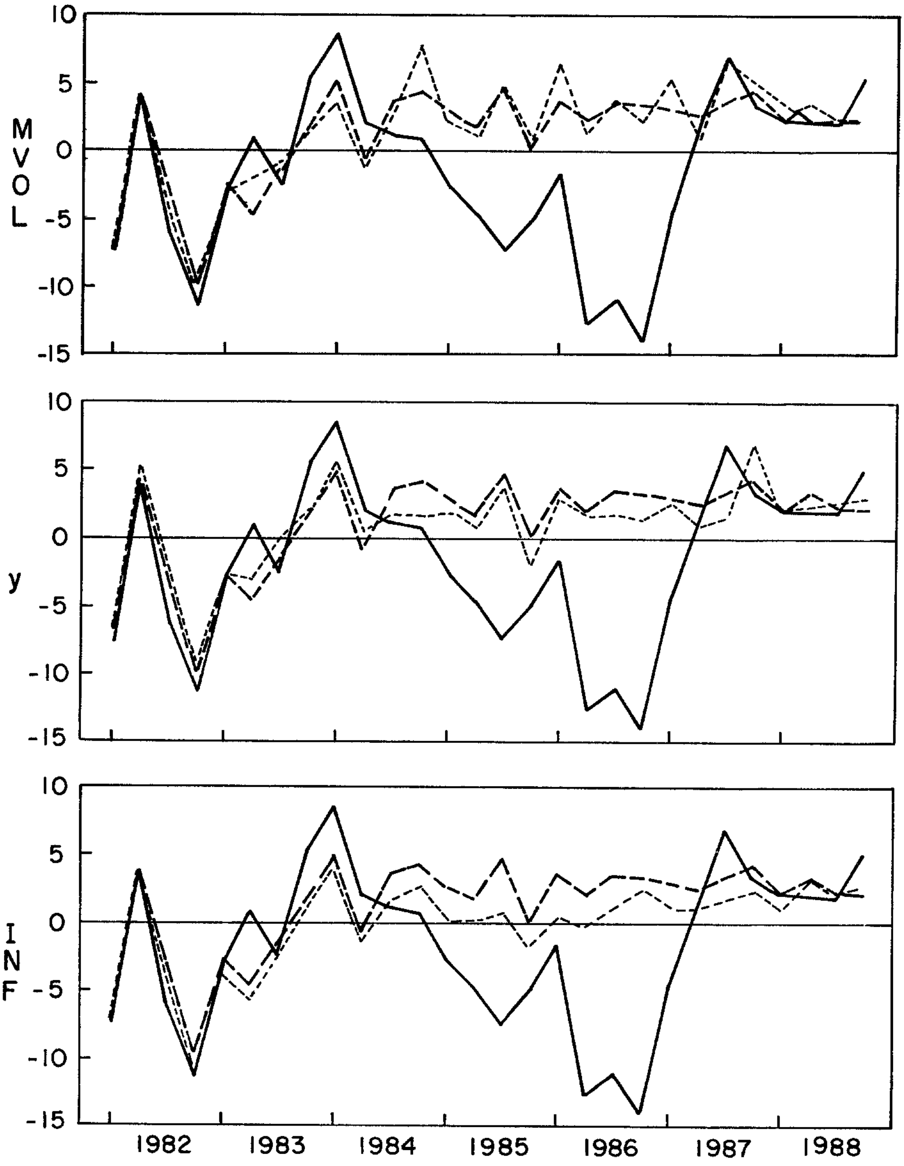

Figure 1. Historical Decompositions for V1

series than do the other variables. This is especially true for *AAA*. Figure 3 presents the results of adding the shocks to all the non-*V1* variables to the BP. We note that the interaction among these variables is such that the line representing the BP plus the contribution of these variables is much closer to the actual series than is the BP line. Most of the sharp turning points are picked up by considering all non-*V1* shocks simultaneously.

Table III summarizes the results of the HD. The root-mean-square errors (RMSE's) for the BP are presented, as are the RMSE's for BP plus the contribution of shocks to each of the other variables. The ratio of the RMSE for BP plus the contribution of each variable to the RMSE for BP is in parentheses. We observe that, with the exception of *MVOL*, the addition of the shock

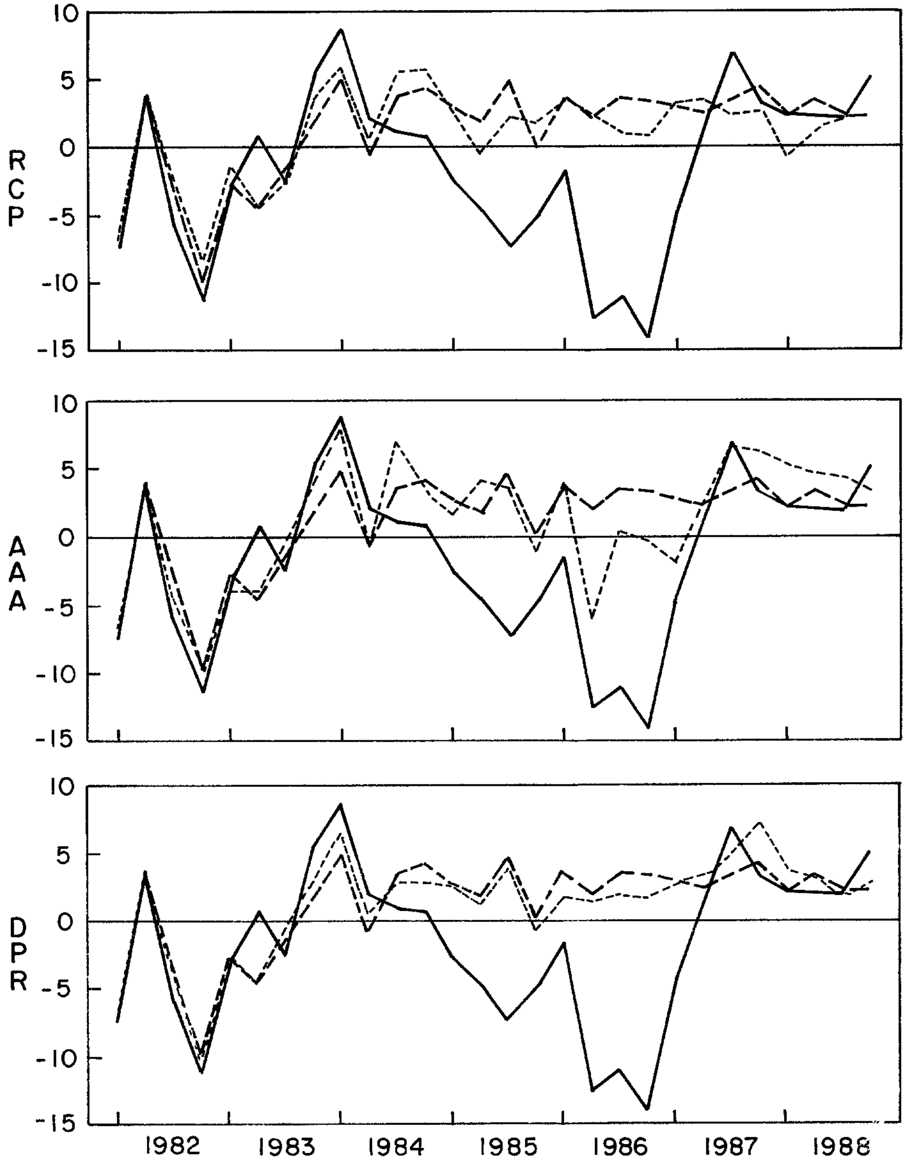

Figure 2. Historical Decompositions for V1

to each variable to the BP reduces the RMSE relative to that of the BP alone. Although *MVOL* clearly helps explain the movement in velocity over 1982-mid-1983 (Figure 1), its poor performance thereafter results in a RMSE for the BP plus *MVOL* shocks that is essentially identical to that of the BP alone.[15] The *AAA* rate alone reduces the BP RMSE by 20%. Each of the remaining variables individually reduces the BP RMSE by 8–14%. Addition of the shocks to the three yield

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[15] When RMSE's are computed for 1982–1983, addition of *MVOL* shocks to the BP reduce the BP RMSE by 23%. However, for 1984–1988, the ratio of the BP + *MVOL* RMSE to that of the BP alone is 1.02.

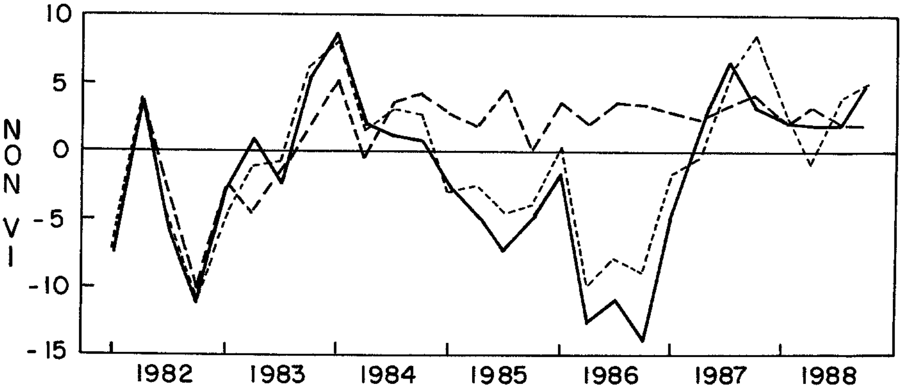

Figure 3. Historical Decompositions for V1

Table III. Summary of Historical Decomposition Results[a,b]

	Root-Mean-Square Errors 1982:1–1988:4
BP	6.47
BP + *MVOL*	6.51 (1.01)
BP + *y*	5.88 (0.91)
BP + *INF*	5.56 (0.86)
BP + *RCP*	5.98 (0.92)
BP + *AAA*	5.16 (0.80)
BP + *DPR*	5.90 (0.91)
BP + *RCP* + *AAA* + *DPR*	3.99 (0.62)
BP + shocks to the non-*V1* variables	2.26 (0.35)

a. The BP line refers to the root-mean-square errors for the base projection. The remaining lines refer to the root-mean-square errors for the base projection plus the contribution of shocks to each variable.

b. The numbers in parentheses are the ratios of the root-mean-square errors for the base projection plus the contribution of shocks to each variable to the root-mean-square errors for the base projections.

variables reduces the BP RMSE by 38%. As expected from Figure 3, simultaneous addition of the shocks to the non-*V1* variables reduces the BP RMSE by 65%.

The HD's and VDC's reveal some similarities and some differences between the periods 1961:1–1981:4 and 1982:1–1988:4. Both the VDC's and the HD indicate that the collective effects of the other six variables of velocity on velocity are quite strong. However, a ranking of the variables in terms of relative importance in explaining velocity based upon the VDC's differs in many ways from a ranking based on the HD's. For the VDC's (20-quarter horizon), the economic determinants are ranked *AAA*, *y*, *RCP*, *MVOL*, *DPR*, and *INF* in order of importance to explaining velocity. The ranking for the HDs is *AAA*, *INF*, *y* and *DPR*, *RCP*, and *MVOL*. Both rankings place *AAA* at the top, but the order differs after this. These results are suggestive of a shift in the process generating velocity.

As a consequence of the HD results, the stability of the process generating velocity was formally tested. A straightforward multivariate extension of the procedure suggested by Dufour [9; 10] was performed. In the single equation variant of Dufour's test, a 0–1 dummy is added for *each* observation in the period in which instability is suspected. The dummy takes on a value of 1 for one particular observation and 0 for all other observations. In the current case, the period of suspected instability is 1982:1–1988:4; thus the test would require adding 28 dummies to the equation to be tested. The coefficients on a particular dummy variable measure the prediction error for that observation.[16] The equation is estimated over the full sample and the joint significance of the coefficients on the dummies is tested. Rejection of the null hypothesis that the coefficients on the dummies are jointly equal to zero is indicative of instability.

In the multivariate extension of this test, the system was first estimated with 8 lags on each variable over 1961:1–1988:4. Dummy variables for each observation in 1982:1–1988:4 were then added to *each* equation in the system, and this system was estimated over 1961:1–1988:4. The joint significance of the coefficients on all the dummy variables was tested by a likelihood ratio test. The test statistic

$$T \cdot (\log |\mathbf{DR}| - \log |\mathbf{DUR}|)$$

was formed where $|\mathbf{DR}|$ = determinant of the variance-covariance matrix of the restricted system, $|\mathbf{DUR}|$ = determinant of the variance-covariance matrix of the unrestricted system (system with the dummy variables), and T = number of observations in the sample period 1961:1–1988:4. This statistic is distributed as χ^2 with degrees of freedom equal to the number of restrictions (i.e., the number of coefficients on the dummy variables which equals 196 in this case). The calculated χ^2 statistic was 887.38 which is significant at the 1% level. Thus the hypothesis that the coefficients on the dummy variables are jointly equal to zero is easily rejected, and a shift in the process generating velocity after 1982 is indicated.

The multivariate Dufour test indicates instability in the process generating velocity but gives no indication of the source of the instability. As a consequence, a test suggested by Christiano [5] is used to determine whether the coefficients on a particular variable shifted after 1982. In implementing this procedure, a dummy variable that takes on the value of 1 in the 1982:1–1988:4 period and 0 in all other periods is first constructed. Interaction dummy variables for a particular variable in the VAR model are constructed by multiplying the dummy variable times the lagged values of the variable in all equations of the system. The system is estimated with and without these interaction dummy variables over the period 1961:1–1988:4. A likelihood ratio test of the

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[16] The equation to be estimated is:

$$y_t = b_0 + \sum_{k=1}^{n_1} \sum_{j=1}^{n_2} b_{kj} X_{k,t-j} + \sum_{s=T_1+1}^{T} a_s D_{st} + u_t$$

where

t = $1, \ldots T$,
T = number of observations in the full sample,
T_1 = last observation prior to the period of suspected instability,
b_{kj} = coefficient on the jth lag of variable k,
n_1 = number of variables,
n_2 = lag length, and
D_{st} = 1 for $t = s$
= 0 for $t \neq s$.

As Dufour [9] notes,

$$a_s = E(y_s) - b_0 - \sum_{k=1}^{n_1} \sum_{j=1}^{n_2} b_{kj} X_{k,s-j}.$$

This is the prediction error for this observation.

Table IV. Stability Test Results[a]

Test	Degrees of Freedom	χ^2 Statistic
Intercept Shift	7	23.71 (.001)
AAA Coefficient Shift	56	153.57 (.00)
RCP Coefficient Shift	56	132.78 (.00)
DPR Coefficient Shift	56	200.36 (.00)
INF Coefficient Shift	56	131.28 (.00)
y Coefficient Shift	56	220.47 (.00)
MVOL Coefficient Shift	56	192.05 (.00)
V1 Coefficient Shift	56	164.35 (.00)

a. The marginal significance level is in parentheses next to the calculated χ^2 statistic.

joint significance of the coefficients on the interaction dummy variables is performed with the test statistic constructed in an analogous fashion to that in the Dufour test. Again the restricted system is the system without the dummy variables and the unrestricted system includes the dummy variables. The test statistic is distributed as χ^2 with degrees of freedom equal to the number of interaction dummy variables. The degrees of freedom for the test for a particular variable is 56 (the product of the number of lags of a variable in an equation (8) and the number of equations (7)). The results of the tests for each variable are reported in Table IV. Also included is a test for the intercept term. The results indicate that the null hypothesis that the coefficients on the interaction dummy variables are jointly equal to zero can be rejected for each variable and for the intercept. The instability for the process does not appear to stem from instability in the coefficients on just one or even just a few of the variables in the system, but instead appears to stem from a shift in the coefficients on all the variables in the system.

IV. Summary and Conclusion

The aim of this paper has been to examine the behavior of velocity before and after 1982. The basis of the analysis is a velocity function similar to that of Friedman [15]. In the specific function considered, velocity depends upon output, a short-term interest rate, a long-term interest rate, the yield on equities, inflation, and money ($M1$) growth variability. A vector autoregressive model that contains these variables along with velocity was then specified. The impact of the economic variables on velocity was assessed by computing variance decompositions and a historical decomposition. A Monte Carlo simulation technique was employed to estimate standard errors for the variance decompositions. The variance decompositions indicated significant effects of each of the economic variables on velocity for the 1961:1–1981:4 period. It is worth stressing that each of the three yield variables separately had a significant effect on velocity, and their joint effect was quite important.

The historical decomposition was computed for the 1982:1–1988:4 period of unusual velocity behavior. The historical decomposition indicated that the economic determinants of velocity were jointly important in explaining velocity in the 1982:1–1988:4 period. However, the relative importance of the economic variables in determining velocity was different from the variance decompositions. Both the variance decompositions and historical decompositions rank *AAA* as the most important single variable in explaining velocity, but the rankings in terms of relative importance differ for the other variables.

The disparity in the results for the historical decomposition and the variance decompositions is suggestive of instability in the process generating velocity. The possibility of instability is investigated through formal stability tests suggested by Dufour [9; 10] and Christiano [5]. The Dufour test is employed to determine whether the process as a whole shifted and the Christiano test is used to determine whether the coefficients on particular variables shifted. The Dufour test indicated a shift in the process generating velocity, and the Christiano tests indicated the instability stems from a shift in the coefficients on all the economic determinants of velocity. This paper thus concludes that the misbehavior of the velocity of $M1$ in recent years stems from a shift in the process generating velocity and does not merely reflect unusual variability in the determinants of velocity.

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