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Will the U.S. Velocity of Money Step up Again? New Evidence from the Random Walk Hypothesis

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Will the U.S. Velocity of Money Step up Again? New Evidence from the Random Walk Hypothesis

Abstract

The recent decrease in U.S. money velocity raises debates about its unit root behavior. This paper revisited the random walk hypothesis (RWH) of the U.S. money velocity in 1960-2010 and two sub-periods 1960-85 and 1986-2010 by applying the Variance Ratio methodologies, including new nonparametric tests by Wright (2000) and Belaire-Franch and Contreras (2004). The results suggested that the velocity would likely increase, and the U.S. monetary policy will soon stimulate GDP and employment. Furthermore, past velocity is important to predict the future outcomes, and changes in financial structural could alter the empirical characteristics of the velocity series.

Keywords

velocity of money, random walk, variance ratio test, money redefinition

Cover Page Footnote

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1 Introduction

Velocity of money is the rate at which circulated money is used for purchasing goods and services, or the turnover rate of money supply. It reflects the state of spending and investing behaviors, and is an indicator of money demand. The behavior of money velocity plays an important role in monetary theory and policy, yet its specifications are controversial among schools of thoughts. While classical models view velocity of money as a constant, Keynesians see it negative correlated to interest rates. Modern monetarists, however, claim that velocity of money is a stable function of macroeconomic determinants.

The stability of money velocity is necessary to any assumptions in monetary models and central bank policy. Nevertheless, a recent study by Hartman (2012) mentions the prolonged fall in the U.S. money velocity. This unusual behavior breaks the relationship between money and income. It is the reason why an abundant money supply has not stimulated the U.S. economic recovery and the employment rates. Would the U.S. money velocity remain stable? Would it continue to fall or eventually rise back to its long-term trend? Finally, could scholars still predict its behavior based on historical data?

One method to answer those questions is testing the random walk hypothesis. A random walk implies a difference stationary (DS) process, which is not trend-reverting. Haraf (1986) demonstrated that

> Shocks to a variable that follows a DS process have a permanent effect on the level of the variable. Therefore, events will influence long-term forecasts... the uncertainty about the future level of the series increases without bound as the forecast horizon lengthens (p. 648).

The random walk model predicates on independent successive increments over time, meaning that only the most recent values, not past data, can be used to predict future velocity behaviors. The random walk hypothesis was based on Irving Fisher's treating the velocity of money as a black box, eliminating the complex structural equation. It helps the research focus solely on the money velocity, not other economic variables, to determine its characteristics. A random walk, or difference stationary, relationship implies that possible economic shocks resulted in the money velocity moving in different direction and unlikely to come back to its previous trend. The fall of velocity might continue for a long time unless other shocks were introduced.

Empirical analysis often considers different definitions of money aggregates: M1 emphasizes the transaction demand of money, and M2 focuses on the asset alternative property of money. This research used both velocities of M1 and M2.

In this paper, the author tested the RWH of the U.S. velocity of money in 1960-2010, using quarterly and annual data. The research also looked at two sub-periods of 1960-1985 and 1986-2010. This division was based on the time period of deregulations and changing money measurements that occurred in the early 1980s. Choosing the mid-1980 breakpoint, the author estimated that those changes took full effect in the U.S. money aggregates. The methodology centers on the Variance Ratio Tests, which were considered the best procedures for testing the random walk. The traditional tests by Lo and Mackinlay (1988) (hereafter, LOMAC) and Chow and Denning (1993) (hereafter, CHODE) were performed. In addition, the author implemented nonparametric tests by Wright (2000) and Belaire-Franch and Contreras (2004), which did not appear in previous testing of the money velocity's RWH.

Outline The organization of the paper as follows. Section 2 provides previous work on the random walk hypothesis of the velocity of money. Section 3 details the data, the random walk model, and the specifications of the variance ratio tests. The empirical results are presented in Section 4. Section 5 has discussion and conclusion. Section 6 provides all the result tables.

2 Literature Review

Whenever the velocity of money behaved irregularly, many studies searched to find its stochastic characteristic and predictability. The goal was to determine the relationship between money and national output. The fall of the U.S. money velocity in the post-World War II period and its instability in the 1980s initiated various time-series models capturing velocity behaviors, including the well-known random walk. However, most research did not reach a consensus of whether velocity followed a random walk.

After the post-war decline in the velocity of money, Gould and Nelson (1974) were pioneers in examining the random walk hypothesis on the velocity of money, explaining the statistical basis for extrapolative prediction (p. 405). They analyzed the velocity series constructed by Milton Friedman and Anna Schwartz by examining its autocorrelations within the autoregressive-moving average (ARMA) models. They found that the annual data of U.S. velocity of money was well characterized by the simple random walk, yet the quarterly data did not support the hypothesis. In other literatures by Gould et al. (1978), Nelson and Plosser (1982), and Akhing (1982), the U.S. money velocity was first-difference stationary, implying that the velocity might go off to a different route (due to large shocks) without wandering back to its trend. In contrast, Meltzer (1963) and MacDonald and Peel (1986) argued that the velocity of money might be more complex than the simple random walk.

Similarly, the 1980s unstable velocity intrigued many stochastic analyses. Haraf (1986), Friedman and Kuttner (1992), Serletis (1995), and Karemera, Harper and Oguledo (1998) provided evidence of a random walk in the U.S velocity of money. Siklos (1993), Choudhry (1996), Mehra (1997), and Anderson and Rasche (2001), on the other hand, showed stability in the series. Shirvani and Delcoure (2012) conducted the most recent study on difference stationary and trend-reverting money velocity. The research rejected the RWH.

Theoretically, both money aggregates and national income could be the sources of randomness in the money velocity. McCulloch (1975) found random walk evidence in aggregate income. Campbell and Mankiw (1987) also suggested high fluctuations in national output as a consequence of the random walk. Likewise, Leijonhuvud (1984) proved that U.S. money aggregates were a first-difference stationary process, dominated by a random walk. Furthermore, the random component of money velocity might come from other different factors and their interactions, such as money demand, interest rates, and expected inflation rates. Indeed, Bardo and Jonung (1987) claimed that it might be impossible to distinguish individual causes for the underlying series. Treating the velocity of money as a black box in random walk testing would be better for the research.

Among alternative random walk tests, the Variance Ratio Test proved to be a better choice than the traditional unit root tests by Box and Jenkins and Dickley-Fuller. Focusing on uncorrelated increments and autocorrelations, which had important economic implications, the test was acknowledged to be more robust to the stochastic characteristics of random walks. Karemera, Harper and Oguledo (1998) first introduced this method into testing money velocity. Their analysis emphasized the single hypothesis variance ratio test by Lo and Mackinlay (1988) as well as the multiple variance ratio tests by Chow and Denning (1993).

Over the past decade, researchers developed new techniques in variance ratio tests, notably the Wright (2000)'s nonparametric tests using ranks and signs and the multiple nonparametric variance ratio tests by Belaire-Franch and Contreras (2004). Nonparametric tests required no normality assumptions of the error terms. Unfortunately, due to the decreased attention to money velocity, none of the recent studies considers nonparametric testing of the RWH in the velocity series. Renewing attention to the stochastic structure of U.S. velocity of money is necessary concerning the stagnant growth and low employment of the U.S. economy. With the new advances in variance ratio tests, it is worth retesting the random walk hypothesis of the velocity process.

3 Methodology

3.1 The Random Walk Model

Define V_t as the log of money velocity at time t. The random walk model is presented in the following recursive equation

$$V_t = \mu + V_{t-1} + \epsilon_t \tag{1}$$

where μ is the unknown drift parameter, and ϵ_t is the random disturbance term at t. The traditional random walk requires ϵ_t to follow the Gaussian white noise process. Mathematical assumptions for ϵ_t are $E(\epsilon_t) = 0$, $E(\epsilon_t^2) = \sigma_\epsilon^2$, and $E(\epsilon_t \epsilon_{t'}) = 0$ for $t \neq t'$.

3.2 The Variance Ratio Tests

First developed by Lo and Mackinlay (1988), the variance ratio tests exploit the key fact that if a series is random walk, its variance of k-period difference, $V_t - V_{t-k}$ is k times the variance of the first difference, $V_t - V_{t-1}$. The variance ratio is

$$V(k) = \frac{1}{k} \frac{var(V_t - V_{t-k})}{var(V_t - V_{t-1})} \tag{2}$$

Under the null hypothesis that V_t is a random walk, $V(k) = 1$.

3.2.1 Lo and MacKinlay (1988): single parametric tests

Giving $nk+1$ observations $V_0, V_1, ..., V_{nk}$, LOMAC defined the following unbiased estimators

$$\hat{\mu} = \frac{1}{nq}\sum_{t=1}^{nk}(V_t - V_{t-1}) = \frac{1}{nk}(V_{nk} - V_0) \tag{3a}$$

$$\hat{\sigma}_k^2(k) = \frac{1}{nk-1}\sum_{t=1}^{nk}(V_t - V_{t-1} - \hat{\mu})^2 \tag{3b}$$

$$\hat{\sigma}_1^2(k) = \frac{1}{m}\sum_{t=1}^{nk}(V_t - V_{t-1} - k\hat{\mu})^2 \tag{3c}$$

$$m = k(nk - k + 1)\left(1 - \frac{k}{nk}\right) \tag{3d}$$

The unbiased estimator of variance ratio is

$$VR(k) = \frac{1}{k}\frac{\hat{\sigma}_k^2(k)}{\hat{\sigma}_1^2(k)} \tag{4}$$

Under the RWH that $V(k) = 1$, LOMAC designed test statistics according robust to homoscedasticity and conditional heteroscedasticity. With homoscedasticity, the test statistic

$$M_1(k) = \frac{VR(k) - 1}{\phi(k)^{1/2}} \tag{5}$$

asymptotically follows the standard normal distribution, where the asymptotic variance is

$$\phi(k) = \frac{2(2k-1)(k-1)}{3k(nk)} \tag{6}$$

Likewise, the heteroscedasticity-consistent test statistic

$$M_2(k) = \frac{VR(k) - 1}{\phi^*(k)^{1/2}} \tag{7}$$

also asymptotically follows the standard normal distribution, where

$$\begin{aligned} \phi^*(k) &= \sum_{j=1}^{k-1} \left[\frac{2(k-j)}{k}\right]^2 \delta(j) \qquad (8) \\ \delta(j) &= \frac{\sum\limits_{t=j+1}^{nk} (V_t - V_{t-1} - \hat{\mu})^2 (V_{t-j} - V_{t-j-1} - \hat{\mu})^2}{\left[\sum_{t=1}^{nk} (V_t - V_{t-1} - \hat{\mu})\right]^2} \end{aligned}$$

3.2.2 Chow and Denning (1993): multiple parametric tests

The LOMAC tests are appropriate for testing individual variance ratios for a given value of k, by comparing M_1 and M_2 with the critical values of the standard normal table. Nevertheless, CHODE (1993) pointed out that this method required testing variance ratios of all k values equal to 1, and the joint tests are performed. Multiple tests without controlling test size could cause large probability of Type I error and data-snooping bias (Chow and Denning 1993, p. 386). Therefore, CHODE (1993) proposed a multiple hypothesis test of the set of VR estimates with unity while controling the test size. The new tests reduce the statistical disavantages, and are hence more powerful than the LOMAC tests. The CHODE (1993)'s joint test statistics are

$$CD_1 = \sqrt{nk} \max_{1 \leq i \leq m} |M_1(k_i)| \qquad (9a)$$

$$CD_2 = \sqrt{nk} \max_{1 \leq i \leq m} |M_2(k_i)| \qquad (9b)$$

where $M_1(k_i)$ and $M_2(k_i)$ are determined in (5) and (7), respectively.

CHODE (1993)'s procedure used the Sidak (1967) probability inequality and Hochberg (1974) and Richmond (1982)'s research to control the multiple variance-ratio tests. They proved that the statistic followed the Studentized Maximum Modulus (SMM) distribution with m (number of k values) and N (sample size) degrees of freedom. The rejection rule for RWH was at the α level of significance when the M_1 or M_2 statistic was greater than the $[1 - (\alpha^*/2)]$ percentile of $N(0, 1)$, where $\alpha^* = 1 - (1 - \alpha)^{1/m}$.

3.2.3 Wright (2000): single nonparametric tests

The major disadvantage of using LOMAC (1988) and CHODE (1993) methods is that they are asymptotic tests whose sampling distributions are limited in finite samples. Wright (2000) mentioned that the distributions were quite asymmetric and nonnormal, leading to mixed results that were sensitive to choices of k. Therefore, Wright (2000) designed nonparametric variance-ratio tests, as alternatives to traditional LOMAC's (1988), using ranks and signs. Two benefits of rank- and sign-based tests, Wright (2000) argued, were using exact distributions and being powerful in case of highly nonnormal data.

Under the homoscedasticity assumption, Wright (2000) proposed the rank-based tests. Let $\{y_t\}_{t=1}^{T}$ be the first differences of $\{V_t\}$. Define $r(y_t)$ be the rank of y_t among $y_1, y_2, ..., y_T$, and

$$r_{1t} = \left(r(y_t) - \frac{T+1}{2}\right) \div \sqrt{\frac{(T-1)(T+1)}{12}} \tag{10a}$$

$$r_{2t} = \Phi^{-1}\left(\frac{r(y_t)}{T+1}\right) \tag{10b}$$

The ranked-based statistic is

$$R_1 = \left(\frac{\frac{1}{Tk}\sum_{t=k+1}^{T}(r_{1t} + r_{1t-1} + ... + r_{1t-k})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{1t}^2} - 1\right) \times \phi(k)^{-1/2} \tag{11}$$

$$R_2 = \left(\frac{\frac{1}{Tk}\sum_{t=k+1}^{T}(r_{2t} + r_{2t-1} + ... + r_{2t-k})^2}{\frac{1}{T}\sum_{t=1}^{T} r_{2t}^2} - 1\right) \times \phi(k)^{-1/2} \tag{12}$$

The critical values of R_1 and R_2 can be obtained by simulating their exact sampling distributions. For the conditional heteroscedasticity case, suppose $s_t = 2u(y_t, 0)$, and $s_t(\bar{\mu}) = 2u(y_t, \mu)$, where

$$u(y_t, q) = \begin{cases} 0.5 & \text{if } y_t > q \\ -0.5 & \text{otherwise} \end{cases} \tag{13}$$

Then the test statistic for zero-drift assumption, i.e. $\mu = 0$ is

$$S_1(k) = \left(\frac{\frac{1}{Tk}\sum_{t=k+1}^{T}(s_t + s_{t-1} + ... + s_{t-k})^2}{\frac{1}{T}\sum_{t=1}^{T} s_t^2} - 1\right) \times \phi(k)^{-1/2} \tag{14}$$

while the test statistic for unknown drift assumption is

$$S_2(k) = \left(\frac{\frac{1}{Tk}\sum_{t=k+1}^{T}(s_t(\bar{\mu}) + s_{t-1}(\bar{\mu}) + ... + s_{t-k}(\bar{\mu}))^2}{\frac{1}{T}\sum_{t=1}^{T} s_t(\bar{\mu})^2} - 1\right) \times \phi(k)^{-1/2} \tag{15}$$

Similar to R_1 and R_2, S_1 and S_2 follow their exact sampling distributions.

To compute S_2, apply Luger (2003) procedure of using ranks and signs to extend Campbell and Dufour (1997) nonparametric test of random walk with unknown drift, as described in Belaire-Franche and Contreras (2004) study.

3.2.4 Belaire-Franche and Contreras (2004) (Joint Wright): multiple nonparametric tests

Although Wright's (2000) variance ratio tests are more powerful because they do not rely on asymptotic behaviors, they still have some problems of multiple comparisons, especially the over rejection of the null hypothesis in a joint test. As a result, Belaire-Franche and Contreras (2004) implemented CHODE's (1993) procedure and Wright's (2000) method to create multiple rank and sign variance ratio tests, which are

$$CD_{(R_1)} = \max_{1\leq i\leq m} |R_1(k_i)| \tag{16a}$$

$$CD_{(R_2)} = \max_{1\leq i\leq m} |R_2(k_i)| \tag{16b}$$

$$CD_{(S_1)} = \max_{1\leq i\leq m} |S_1(k_i)| \tag{16c}$$

$$CD_{(S_2)} = \max_{1\leq i\leq m} |S_2(k_i)| \tag{16d}$$

The rank-based tests are exact under the homoscedasticity condition, whereas the sign-based tests are exact under both homoscedasticity and heteroscedasticity condition. Besides, the rank-based tests are more powerful than the sign-based ones.

3.3 Data

The research retrieved both quarterly and annual velocity data from the FRED site by Federal Reserve Bank of St. Louis. The velocity of money was computed as the ratio of income over money stock. This study used the GDP definition of income, which was considered universal in all current research. Two alternative definitions of money aggregates are M1 and M2. The author focused only on data after 1960, when the Federal Reserve Board started publishing official monetary aggregates. Although Friedman and Schwartz (1971) recorded their own 1869-1960 velocity of money, that series was not considered in this study due to its questionable reliability.

3.4 Sub-period Analysis

One important theory in random walk analysis is that different time periods might affect results of the random walk test. Stokes and Neuburger (1979) showed that using a more homogeneous period, the money velocity did not follow a random walk. Gould et al. (1978) also proved that the random walk hypothesis was sensitive to different time aggregations. However, Ahking (1982) later rejected the theory by using end-of-period data.

The theory shed light on reexamining the money velocity series not only in a long period, but also in smaller periods that account for significant changes. Throughout the history of U.S. money from 1960, introduction of new innovations since mid-1970s reformed the financial markets as well as the role of money. Money evolved from a medium of exchange to an alternative low-risk asset. This change required a redefinition of money aggregates to reflect the current portfolio structure for households and businesses. In 1980, the Depository Institution Deregulation and Monetary Control Act (DIDMCA) came out allowing money stock to include accounts from other thrift institutions besides commercial banks. Later, the Garn-St. Germain Act (1982) permitted thrifts to have wider commercial and consumer lending, along with the offering of money market deposit accounts (MMDAs). This act helped expand new sections of money aggregates. The new definition then fully accounted for the structural changes in the financial markets, and velocity of money consequently mirrored the new change.

Therefore, it is useful to segment the 1960-2010 into two sub-periods of 1960-1985 and 1986-2010. Although the 1980s redefinition of money required the Federal Reserve to recalculate previous data, the before-1985 data may not accurately reflect all new components of the money stock.

4 Results

4.1 The 1960-2010 Period

Table 1 and 2 showed the test results for the 1960-2010 velocity series. In Table 1, the LOMAC section included the estimates of the variance ratios, the M_1 and M_2 statistics, respectively under homoscedasticity and heteroscedasticity. These statistics were computed for 2, 4, 8, and 16 observation intervals. The CHODE section provided the multiple hypothesis statistics CD_1 and CD_2, computed from the M_1 and M_2 statistics of the stated intervals.

Likewise, the results of Wrights and Joint Wrights tests were presented in Table 2. In the Wright section, the ranked R_1 and R_2 statistics assumed homoscedasticity, whereas the signed S_1 and S_2 statistics assumed heteroscedasticity. The procedure used the same set of observation intervals as LOMACs. It is necessary to note that S_1 assumed the zero drift, yet S_2 was generalized into unknown-drift cases. However, to compensate for less assumptions, S_2 became a more conservative test, as warned by Wright (2000). The Joint Wright section applied the Belaire-Franche and Contreras (2004) method using Wrights test results.

The symbol '*' implied that the variance ratio is statistically significant from 1.0 at the 5% confidence level. In the LOMAC, the homoscedastic and heteroscedastic tests were compared with 1.96 critical value of the standard normal distribution. In the CHODE, the critical value was 2.491, which came from the S.M.M. distribution. The critical values for Wright and Joint Wright tests were generated from their exact distributions with 10000 iterations.

Both tables indicated that the 1960-2010 statistics rejected the null hypothesis of random walk. In LOMAC and Wright, the hypothesis was immediately rejected when $k = 2$, the shortest interval. The nonparametric Wright and Joint Wright tests even emphasized stronger evidence of rejecting the RWH.

4.2 The 1960-1985 and 1986-2010 Sub-periods

The research found contrasting results in the two sub-periods. Table 3 and 4, similar to Table 1 and 2, reported the results for the 1960-1985 series. The computed variance ratios were not statistically significant from 1.00. The statistics in both parametric and nonparametric tests, especially of the annual data, supported the RWH.

Similarly, Table 5 and 6 showed the statistics of 1986-2010. In contrast to the previous period, the 1986-2010 period strongly rejected the RWH. All quarterly statistics were 5% statistically significant. For annual statistics, only the signed-based tests failed to reject the annual M2 velocity.

Overall, the annual data was more likely to follow the random walk under nonparametric heteroscedasicity-robust tests. The M2 velocity supported the RWH in more cases than the M1 velocity did. In most cases, both the parametric and nonparametric tests yielded the same conclusions. The only exception was M2 velocity, in which the signed-based Wright and Joint Wright's tests supported the random walk. These differences were possibly due to different money definitions, time periods, and model characteristics. The broader the money definition, the longer time span the velocity represented, and the more heteroscedastic the procedure, the more likely the statistics supported the RWH.

5 Discussions and Conclusions

The Variance Ratio test results showed that the U.S. velocity of money in 1960-2010 and in 1986-2010 rejected the random walk hypothesis, while the 1960-1985 period failed to reject the hypothesis. The results proposed a stable and predictable U.S. velocity of money, which implied that past velocity data could be used to predict its future outcomes. Furthermore, there was enough evidence to show a steady relationship between U.S. monetary aggregates and national output. The increase in monetary aggregates will usually stimulate more economic output and employment.

The sub-period analysis showed that the early 1980s money redefinition significantly altered the random walk behavior of velocity of money. The 1960-1985 period failed to reject the RWH. The new definition included other types of money assets and accounted for the structural changes in the U.S. financial markets. The 1986-2010 velocity became more stable and predictable. As Schwartz (1985) once argued, significant financial innovations in the economy introduced more randomness into the velocity of money. The money redefinition could be the main explanation for the contradictions in the results of the random walk analysis of money velocity. Many 1960s and 1980s studies used the old money definition, which might not fully reflect all the structural changes in the financial markets. They supported the RWH, while most of the recent ones with the new velocity rejected the hypothesis.

Despite the Fed's substantial quantitative easings, the U.S. economy still slowly recovered since 2009-2010. This was due, in part, to the prolonged fall in the velocity of money. Will the velocity get higher again? The rejection of the RWH suggested that the velocity series was trend-reverting. Any shocks introduced to the system would not deviate it from the established trend. The 2007-2008 financial crisis was an important factor of the fall in U.S. money velocity, yet that shock was only temporary. In the near future, the velocity will likely increase back to its previous trend. Therefore, providing the current monetary policy, the U.S. output and employment will largely increase within a few years.

Although the results concluded a predictable money velocity in the long run, they did not imply a specific model to predict future outcomes. Future research will have to investigate the possible directional shift in the velocity of money and its underlying trend. In addition, it is important to study the velocity of money effect on the changing definitions of money over time.

6 Tables

Table 1: Variance Ratio Parametric Test Results: 1960-2010

			LOMAC				CHODE	
Frequency	Velocity		$k = 2$	$k = 4$	$k = 8$	$k = 16$		
Quarterly	M1V	VR	1.556	2.439	3.558	3.465		
		M_1	(7.916)*	(10.957)*	(12.321)*	(7.978)*	CD_1	(12.321)*
		M_2	[4.234]*	[6.375]*	[8.451]*	[6.484]*	CD_2	[8.451]*
	M2V	VR	1.445	1.925	2.416	2.372		
		M_1	(6.334)*	(7.046)*	(6.819)*	(4.442)*	CD_1	(7.046)*
		M_2	[3.881]*	[4.855]*	[5.379]*	[3.986]*	CD_2	[5.379]*
Annual	M1V	VR	1.581	1.575	1.548	1.346		
		M_1	(4.108)*	(2.175)*	(1.309)	(0.555)	CD_1	(4.108)*
		M_2	[3.558]*	[2.085]*	[1.345]	[0.599]	CD_2	[3.558]*
	M2V	VR	1.374	1.436	1.581	1.432		
		M_1	(2.647)*	(1.648)	(1.390)	(0.694)	CD_1	(2.647)*
		M_2	[2.248]*	[1.596]	[1.532]	[0.796]	CD_2	[2.248]

Table 2: Variance Ratio Nonparametric Test Results: 1960-2010

			Wright				Joint Wright	
Frequency	Velocity		$k = 2$	$k = 4$	$k = 8$	$k = 16$		
Quarterly	M1V	R_1	7.108*	9.479*	11.040*	7.611*	$CD_{(R_1)}$	11.040*
		R_2	7.103*	9.799*	11.181*	7.524*	$CD_{(R_2)}$	11.181*
		S_1	8.071*	11.442*	14.308*	13.996*	$CD_{(S_1)}$	14.308*
		S_2	4.281*	5.590*	6.074*	3.703*	$CD_{(S_2)}$	6.074*
	M2V	R_1	6.169*	6.615*	6.334*	3.904*	$CD_{(R_1)}$	6.169*
		R_2	5.908*	6.579*	6.191*	3.794*	$CD_{(R_2)}$	6.579*
		S_1	5.124*	5.102*	4.627*	2.280*	$CD_{(S_1)}$	5.124*
		S_2	4.281*	4.765*	4.449*	2.053*	$CD_{(S_2)}$	4.765*
Annual	M1V	R_1	3.243*	1.901*	0.180	-0.699	$CD_{(R_1)}$	3.243*
		R_2	3.489*	1.861*	0.2271	-0.706	$CD_{(R_2)}$	3.489*
		S_1	4.243*	4.536*	4.590*	3.639*	$CD_{(S_1)}$	4.590*
		S_2	1.131	0.756	0.000	0.080	$CD_{(S_2)}$	1.131
		R_2	2.445*	1.505	0.822	-0.498	$CD_{(R_2)}$	2.445*
		S_1	1.414	-0.227	-0.813	-0.980	$CD_{(S_1)}$	1.414
		S_2	0.849	0.076	0.024	0.153	$CD_{(S_2)}$	0.849

Table 3: Variance Ratio Parametric Test Results: 1960-1985

		LOMAC					CHODE	
Frequency	Velocity		$k = 2$	$k = 4$	$k = 8$	$k = 16$		
Quarterly	M1V	VR	1.117	1.188	1.233	1.720		
		M_1	(1.192)	(1.021)	(0.798)	(1.660)	CD_1	(1.660)
		M_2	[0.994]	[0.865]	[0.687]	[1.505]	CD_2	[1.505]
	M2V	VR	1.261	1.447	1.514	1.120		
		M_1	(2.647)*	(2.424)*	(1.765)	(0.276)	CD_1	(2.647)*
		M_2	[2.524]*	[2.305]*	[1.687]	[0.267]	CD_2	[2.524]*
Annual	M1V	VR	1.166	1.773	1.319	2.15		
		M_1	(0.830)	(2.065)*	(0.539)	(1.301)	CD_1	(2.065)
		M_2	[0.615]	[1.621]	[0.477]	[1.349]	CD_2	[1.621]
	M2V	VR	1.120	0.916	0.660	1.362		
		M_1	(0.598)	(-0.224)	(-0.575)	(0.411)	CD_1	(0.598)
		M_2	[0.566]	[-0.222]	[-0.593]	[0.456]	CD_2	[0.593]

Table 4: Variance Ratio Nonparametric Test Results: 1960-1985

			Wright				Joint Wright	
Frequency	Velocity		$k = 2$	$k = 4$	$k = 8$	$k = 16$		
Quarterly	M1V	R_1	1.249	0.388	-0.147	0.209	$CD_{(R_1)}$	1.249
		R_2	0.941	0.435	-0.051	0.352	$CD_{(R_2)}$	0.941
		S_1	4.237*	6.004*	8.044*	10.359*	$CD_{(S_1)}$	10.359*
		S_2	0.493	0.053	0.017	0.062	$CD_{(S_2)}$	0.493
	M2V	R_1	2.639*	2.096	1.030	-0.744	$CD_{(R_1)}$	2.639*
		R_2	2.300*	2.014	1.053	-0.626	$CD_{(R_2)}$	2.300*
		S_1	2.463*	1.317	-0.017	-1.170	$CD_{(S_1)}$	2.463*
		S_2	1.675**	0.895	0.000	0.022	$CD_{(S_2)}$	1.675
Annual	M1V	R_1	-0.037	0.729	-0.472	-1.000	$CD_{(R_1)}$	1.000
		R_2	0.078	0.733	-0.538	-0.949	$CD_{(R_2)}$	0.949
		S_1	3.400	5.238	6.491	4.884	$CD_{(S_1)}$	6.491*
		S_2	0.200	0.107	0.101	0.170	$CD_{(S_2)}$	0.200
	M2V	R_1	0.052	-0.849	-1.117	-0.915	$CD_{(R_1)}$	1.117
		R_2	0.248	-0.608	-1.070	-0.915	$CD_{(R_2)}$	1.070
		S_1	0.600	-0.748	-1.251	-0.977	$CD_{(S_1)}$	1.251
		S_2	0.200	0.107	0.169	0.011	$CD_{(S_2)}$	0.2

Table 5: Variance Ratio Parametric Test Results: 1986-2010

		LOMAC					CHODE	
Frequency	Velocity		$k = 2$	$k = 4$	$k = 8$	$k = 16$		
Quarterly	M1V	VR	1.698	2.750	4.073	4.147		
		M_1	(6.940)*	(9.308)*	(10.338)*	(7.113)*	CD_1	(10.338)*
		M_2	[4.181]*	[6.140]*	[8.148]*	[6.666]*	CD_2	[8.148]*
	M2V	VR	1.669	2.537	3.713	4.642		
		M_1	(6.659)*	(8.172)*	(9.126)*	(8.233)*	CD_1	(9.126)*
		M_2	[3.151]*	[4.533]*	[6.180]*	[6.934]*	CD_2	[6.934]*
Annual	M1V	VR	1.597	1.606	1.461	1.943		
		M_1	(2.926)*	(1.586)	(0.764)	(1.049)	CD_1	(2.926)*
		M_2	[3.381]*	[1.943]	[0.977]	[1.434]	CD_2	[3.381]*
	M2V	VR	1.598	2.060	3.055	2.069		
		M_1	(2.932)*	(2.777)*	(3.403)*	(1.190)	CD_1	(3.403)*
		M_2	[2.553]*	[2.838]*	[4.160]*	[1.562]	CD_2	[4.160]*

Table 6: Variance Ratio Nonparametric Test Results: 1986-2010

			Wright				Joint Wright	
Frequency	Velocity		$k = 2$	$k = 4$	$k = 8$	$k = 16$		
Quarterly	M1V	R_1	7.306*	9.745*	10.814*	6.947*	$CD_{(R_1)}$	10.814*
		R_2	7.080*	9.439*	10.205*	6.401*	$CD_{(R_2)}$	10.205*
		S_1	6.935*	9.455*	11.042*	9.225*	$CD_{(S_1)}$	11.042*
		S_2	5.327*	7.038*	7.662*	4.247*	$CD_{(S_2)}$	7.662*
	M2V	R_1	6.094*	7.259*	8.074*	6.910*	$CD_{(R_1)}$	8.074*
		R_2	6.161*	7.464*	8.174*	6.941*	$CD_{(R_2)}$	8.174*
		S_1	4.523*	5.157*	5.402*	4.116*	$CD_{(S_1)}$	5.402*
		S_2	3.719*	4.781*	5.232*	3.967*	$CD_{(S_2)}$	5.232*
Annual	M1V	R_1	2.460*	0.993	-0.455	-0.855	$CD_{(R_1)}$	2.460*
		R_2	2.461*	1.007	-0.405	-0.852	$CD_{(R_2)}$	2.461*
		S_1	2.041*	0.982	-0.104	-0.464	$CD_{(S_1)}$	2.041*
		S_2	1.225	0.327	0.000	0.070	$CD_{(S_2)}$	1.225
	M2V	R_1	2.541*	2.046*	1.309	-0.889	$CD_{(R_1)}$	2.541*
		R_2	2.642*	2.217*	1.449	-0.854	$CD_{(R_2)}$	2.642*
		S_1	0.816	0.218	0.035	-0.823	$CD_{(S_1)}$	0.823
		S_2	0.816	0.218	0.000	0.093	$CD_{(S_2)}$	0.816

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