A Bootstrap Granger Causality Test between Exchange Rates and Fundamentals

Hsiu-Hsin Ko*

September, 2010

Abstract

This study is in response to the finding of the Granger causality relationship from exchange rates to fundamentals based on the asymptotic test in a previous study, which is taken as evidence for the present-value model for exchange rates. This paper adopts a bootstrap method to reassess the Granger causality evidence. Bootstrap test results show evidence against the finding in the previous work. The Monte Carlo experiment results suggest that the causality test implemented in the previous study tends to spuriously reject null hypotheses. Thus, the existing evidence for the present value model for exchange rates is very weak.

Keywords: bootstrap, Granger causality, the present-value model, exchange rates
JEL classification: F30; F31; C32

*Corresponding Author: Department of Applied Economics, National University of Kaohsiung, No. 700 Kaohsiung University Rd, Nantzu District, Kaohsiung City, Taiwan 811. hhko@nuk.edu.tw +886-7-5916006

1. Introduction

In the past two decades, a great number of researchers have proposed looking for the empirical evidence for the relationship between exchange rates and fundamentals implied by the theoretical models. However, the evidence for the relationship in the relevant literature is rarely significant. The weak relationship between the exchange rate and the macroeconomic aggregate such as money supplies and outputs and the difficulty of linking the exchange rate to the rest of the economy are included as part of the "exchange-rate disconnect puzzle" (Obstfeld and Rogoff, 2000).

In particular, the existence of exchange rate predictability has become an issue since Meese and Rogoff's (1983a, 1983b) finding in the seminal papers, a simple random walk model outperformed all structural models they tested in the out-of-sample forecast for exchange rates. The finding implies that the exchange rate change is nearly unpredictable, and thus, it has inspired many studies to investigate the exchange rate predictability. However, researchers had a hard time to provide a satisfying explanation for why it is so difficult to beat the random walk forecasts of exchange rates. While favorable evidence for exchange rate predictability was found in some empirical studies such as Mark (1995) and Mark and Sul (2001), evidence against exchange rate predictability was also presented in such as Cheung, Chinn and Pascual (2005), Faust, Rogers, and Wright (2003), and Kilian (1999).

In a recent paper, Engel and West (2005) propose a solution to the puzzle. They explain the near-random walk exchange rate by the present-value asset-pricing method in a new direction. In addition to the fundamental we can observe, the exchange rate in the present-value model is also determined by a linear combination of unobservable shocks in fundamentals. They show that the exchange rate is close to a random walk when at least one fundamental follows a unit root process and when the discount factor of the present-value model is close to one. Therefore, the existing empirical finding of near-random walk exchange rate is an implication of the present-value model for exchange rates. However, those findings can only be treated as evidence that is not against the present-value model. There is still a need for direct validations of the present-value model for exchange rates. To do this, Engel and West (2005) evaluate the Granger causality relationship between exchange rates and fundamentals implied by a present-value model.

Inspired by Campbell and Shiller (1987), Engel and West (2005) implement an asymptotic method to test the Granger causality relationship between exchange rates and fundamentals with the VAR model. They find some statistically significant Granger causality relationships from exchange rates to fundamentals, which imply that exchange rates are helpful for predicting fundamentals. Moreover, this finding is consistent with the implication of the present-value asset-pricing model for exchange rates and may change the terms of the exchange rate debates.

Nevertheless, Engel and West's asymptotic test inferences are constructed from three types of sample periods. For two types of the sample periods, the sample size is relatively small. It is known that the asymptotic test method suffers from the small-sample problem in many applications, so Engel and West's results may motivate researchers to re-evaluate the evidence for the present-value model with other testing methods. This paper employs a bootstrap method to reassess the existing evidence of the Granger causality relationship between exchange rates and fundamentals. The reason for conducting the test with the bootstrap method is that the bootstrap method is generally shown to have less size distortion and to provide more precise test inferences than the asymptotic method if the sample size is small in many applications. For example, in a prominent study, Mark (1995) replaces the conventional asymptotic theory method with a bootstrap simulation method to deal with the bias and the size distortion problem in testing models' forecasting performance. He draws the test inferences based on the bootstrap empirical distribution for the test statistic and presents evidence of long-horizon exchange rate predictability. Moreover, owing to advanced computer technology, the bootstrapping technique can be quickly implemented.

In order to compare the new test results from the bootstrap distribution with the existing test results from the asymptotic distribution, the data used in this paper is identical to what have been used in Engel and West's asymptotic test. The test results obtained from two different test procedures becomes more distinct when the sample size used in the test is smaller. In particular, when the smallest sample is applied, fourteen out of thirty null hypotheses, exchange rates do not Granger cause fundamentals, are rejected in the asymptotic tests, but only five out of thirty null hypotheses are rejected in the bootstrap tests.

The Monte Carlo experiment is implemented to examine the robustness of the two types of test methods and to investigate whether the bootstrap test performs better than the asymptotic test in this particular application. Results show that size of the asymptotic Granger causality test is overall lager than that of the bootstrap Granger causality test. Size of the bootstrap test remains around 10% in all of the samples, but the size of the asymptotic test increases to nearly 40% when the sample size is decreased. The increasingly large size of the asymptotic test shows that the size distortion affects the asymptotic test, and it means that the asymptotic Granger causality test tends to spuriously reject the null hypothesis in this application.

The remainder of this chapter proceeds as follows. The next section gives a review of the present-value asset-pricing model for exchange rates and briefly introduces Engel and West's (2005) explanation for the present-value model for exchange rates. Section 3 illustrates the Granger causality test model and the bootstrap algorithms used in this study. Section 4 presents the empirical findings. Section 5 is the robustness test and displays the size of the bootstrap test and that of the asymptotic test. Section 6 is the conclusion of this article.

2. Exchange Rate under the Present-Value Model

2.1 The Conventional Monetary-Income Model for Exchange Rates

An exchange rate can be viewed as an asset price in the present-value model. The flexible exchange rate in the framework of the conventional present-value model is determined by the expectations of future observable fundamentals and the expectation of its own future value. First, we denote the log of the nominal exchange rate measured at time t by s_t and denote the observable macroeconomic fundamentals of the nominal exchange rate measured at time t by f_t. In the conventional money income model, the money market relationship is given by

$$m_t = p_t + \phi y_t - \lambda i_t$$
$$m_t^* = p_t^* + \phi y_t^* - \lambda i_t^*$$

The variable m_t is the log of the money supply, p_t is the log of price level, y_t is the log of income, and i_t is the level of interest rate. The asterisk represents variables in the foreign country. The parameter $0 < \phi < 1$ is the income elasticity of money demand and $\lambda > 0$ is the interest rate semi-elasticity of money demand. The parameters of the foreign money demand are identical to the home country's parameters.

The nominal exchange rate equals its purchasing power parity (PPP):

$$s_t = p_t - p_t^*$$

The financial market equilibrium is given by the uncovered interest parity (UIRP):

$$i_t - i_t^* = \mathrm{E}_t s_{t+1} - s_t$$

Here, $\mathrm{E}_t s_{t+1}$ is the rational expectation of the exchange rate at time $t+1$. Putting the above equations together and rearranging, the present-value formula for the exchange rate takes the form (Mark, 2001, p. 68):

$$\begin{aligned} s_t &= \gamma f_t + \psi \mathrm{E}_t s_{t+1} \\ &= \gamma \sum_{j=1}^{k} \psi^j E_t f_{t+j} + \psi^{k+1} E_t s_{t+k+1} \end{aligned} \tag{1}$$

where

$$f_t \equiv (m_t - m_t^*) - \phi(y_t - y_t^*)$$
$$\gamma \equiv 1/(1+\lambda)$$
$$\psi \equiv \lambda\gamma = \lambda/(1+\lambda)$$

For the no-bubbles solution $(\psi < 1)$, the transversality condition, $\lim_{k\to\infty} \psi^k E_t s_{t+k} = 0$, holds. The later term in the right hand side of equation (1) vanishes. The exchange rate, then, is purely the discounted present value of future fundamentals. In contrast, for the rational bubbles solution, the transversality condition does not hold, and the exchange rate will eventually be governed by explosive bubbles. Yet, in the real world, even if the rational bubble occasionally dominates the exchange rate behavior, the bubble does not last for a long time. Therefore, the rational bubbles solution is not considered in the discussion throughout this paper.

2.2 Engel and West's Explanation for the Present-Value Model for Exchange Rates

In Engel and West (2005), several explanations for why the conventional monetary models for the exchange rate predict no better than a random walk model are proposed. Under their explanation, in addition to the observable fundamental in the conventional model, the exchange rate behavior is also greatly influenced by the present value of the future unobservable fundamentals. According to Engel and West (2005), the exchange rate under the present-value model takes the form:

$$\begin{aligned} s_t &= (1-b)(f_{1t}+z_{1t}) + b(f_{2t}+z_{2t}) + bE_t s_{t+1} \\ &= (1-b)\sum_{j=0}^{\infty} b^j E_t\left(f_{1t+j}+z_{1t+j}\right) + b\sum_{j=0}^{\infty} b^j E_t\left(f_{2t+j}+z_{2t+j}\right) \\ &\quad + b^{k+1}E_t s_{t+k+1} \end{aligned} \tag{2}$$

where b is the discount factor, and z_{t+j} is the unobservable fundamental at time $t+j$. For the no-bubbles solution, we impose the transversality condition, $\lim_{k\to\infty} b^k E_t s_{t+k} = 0$, on equation (2). Equation (2) becomes:

$$s_t = (1-b)\sum_{j=0}^{\infty} b^j E_t\left(f_{1t+j}+z_{1t+j}\right) + b\sum_{j=0}^{\infty} b^j E_t\left(f_{2t+j}+z_{2t+j}\right) \tag{3}$$

Equation (3) provides two explanations for why it is so hard to beat the random walk model in predicting the exchange rate in the previous work. First of all, it is easy to see that, if the exchange rate is governed by the unobserved fundamentals, the exchange rate change will naturally hard to be predicted. Secondly, as pointed out in Engel and West (2005), the value of discount factor value in equation (3) plays an important role in the exchange rate behavior. Under regular conditions, when the discount factor b is close to 1 and at least one fundamental has a unit root process, the correlation of the first-differenced exchange rate is close to zero. Therefore, the present-value model for exchange rates implies that the exchange rate is close to a random walk.

Engel and West's present-value model framework of equation (2) is applicable to many macroeconomic models for exchange rates. We take the money income model as an example. Here, the exchange rate in the money income model equals its PPP value plus the real exchange rate (q_t):

$$s_t = p_t - p_t^* + q_t$$

In addition, consider a shock to the money demand (υ_{mt}) in the money market and a deviation from rational expectations uncovered interest rate parity (ρ_t) in the international capital market. The money market relationship is:

$$m_t = p_t + \phi y_t - \lambda i_t + \upsilon_{mt}$$

The interest parity relationship is:

$$\mathrm{E}_t s_{t+1} - s_t = i_t - i_t^* + \rho_t$$

The analogous foreign variables are m_t^*, p_t^*, y_t^*, i_t^*, and υ_{mt}^*. The parameters of money demand are identical across countries. The exchange rate now can be expressed as:

$$s_t = \frac{1}{1+\lambda}[m - m_t^* - \phi(y_t - y_t^*) + q_t - (\upsilon_{mt} - \upsilon_{mt}^*) - \lambda\rho_t] + \frac{\lambda}{1+\lambda}E_t s_{t+1} \tag{4}$$

Fitting equation (4) into the present-value model framework of equation (2), we can see that the discount factor b in equation (4) of the money income model is $\lambda/(1+\lambda)$, the observed fundamental is $f_{1t} = m_t - m_t^* - \phi(y_t - y_t^*)$, the unobservable fundamentals are $z_{1t} = q_t - (\upsilon_{mt} - \upsilon_{mt}^*)$, and $z_{2t} = -\rho_t$. Under the Engel and West's explanation, the money income model would imply the near-random walk exchange rate if the discount factor $\lambda/(1+\lambda)$ is close to one and at least one fundamental has a unit root process.

In the relevant literature, the value of the discount factor is suggested to be in a range between 0.97 and 0.98 for the quarterly data, which supports Engel and West's argument of the near-one discount factor value for the near-random exchange rate. Hence, the present-value model with the close to one discount factor has an implication that the exchange rate approximately follows a random walk model. However, while the finding of the random walk exchange rate in the empirical studies matches this implication of the model, they can only be considered as evidence not against the model. There is still a need for direct evidence to validate the model.

3. Bootstrap Granger Causality Test

According to Campbell and Shiller (1987), an asset price of the present-value model such as the stock price might help to predict its determinant fundamentals. Testing the Granger causality relationship between the asset price and its determinant variables, therefore, is helpful to find direct evidence for the present-value asset-pricing model. In Engel and West (2005), the authors conduct bivariate and multivariate Granger causality test to evaluate the present-value model for exchange rates. From the asymptotic tests, they find statistically significant Granger causality from exchange rates to fundamentals.

Nevertheless, the type of the data used in Engel and West's study makes the test results questionable. They divide the full sample (1974:Q1 ~ 2003:Q3) into two subsamples in 1990:Q3 due to the evolution of European Monetary Union and the reunion of Germany's economy during this period, and use the full sample as well as the subsamples in the asymptotic Granger causality test. Yet, conducting the asymptotic test with those subsamples may lessen the creditability of the test result because the sample size of all subsamples is very small. For example, the data of France, Germany and Italy all are not available after 1999:Q1, and the number of observations in the later part of sample period (1990:Q3 ~ 2003:Q3) of those countries is merely 34. It is known that the small-sample problem is very likely to occur in this case, and we might need to find more evidence from other testing techniques such as the bootstrap method to confirm the existing evidence for the model.

In response to the asymptotic Granger causality test in Engel and West's (2005) paper, the goal of this article is to re-assess the existing evidence of the present-value model for exchange rates based on the bootstrap empirical distribution. The reason for choosing the bootstrap method is that the bootstrap method is generally believed having less size distortion and providing more precise test inferences than the asymptotic method in many applications if the available sample size is small. Moreover, owing to advanced computer technology, the bootstrapping technique can be quickly implemented.

3.1 The VAR Model for the Granger Causality Test

In order to compare the new test results from the bootstrap test with the existing result from the asymptotic test, the data used in this paper are identical to what Engel and West (2005) used for their asymptotic Granger causality test. In addition, this paper focuses on the bilateral relationship of the U.S. exchange rates against other six countries of G7 members. The fundamental measures include the money supply fundamental $(m_t - m_t^*)$, the output fundamental $(y_t - y_t^*)$, the PPP fundamental $(p_t - p_t^*)$, and the UIRP fundamental $(i_t - i_t^*)$. Following Mark (1995), the income elasticity, ϕ, in the money demand is set to 1, so the monetary fundamental is $(m_t - m_t^*) - (y_t - y_t^*)$. The exchange rate and each of the fundamental measures are shown to maintain unit root processes, so they are presented in the first-differenced form. The data do not show an explicit cointegration relationship between the exchange rate and each fundamental measure, so the VAR model does not include a vector correction term.

The bivariate VAR model in testing the Granger causality relationship between Δs_t and Δf_t takes the form:

$$\begin{pmatrix} \Delta s_t \\ \Delta f_t \end{pmatrix} = \begin{pmatrix} c_s \\ c_f \end{pmatrix} + \sum_{i=1}^{4} \begin{pmatrix} \phi_i^{11} & \phi_i^{12} \\ \phi_i^{21} & \phi_i^{22} \end{pmatrix} \begin{pmatrix} \Delta s_{t-i} \\ \Delta f_{t-i} \end{pmatrix} + \begin{pmatrix} u_{s,t} \\ u_{f,t} \end{pmatrix} \tag{5}$$

where c_s and c_f are the constant terms, and the innovation terms $u_{s,t}$ and $u_{f,t}$ are assumed to be independently and identically distributed (*i.i.d.*) with mean zero and have variances $\sigma_{u,s}^2$ and $\sigma_{f,s}^2$, respectively. The null hypothesis of the Granger causality test between the exchange rate and the fundamental restricts the parameters of s_t or f_t equation in model (5).

For example, the null hypothesis of the non-Granger causality running from the exchange rate to the fundamentals restricts $\phi_i^{21}, i = 1,\ldots,4$ to be zero.

3.2 Bootstrap Test Algorithm

Numerous bootstrap methods have been developed based on different properties of the time series process (Li and Maddala, 1996, 1997; Berkowitz and Kilian, 2000). Because of the simple algorithm in generating bootstrap replications, the residual-based bootstrap has become the most popular one. Under the *i.i.d.* error assumption, one can repeatedly draw residuals and generate the necessary pseudo data.

Since the Jarque-Bera test rejects the null hypothesis of the Gaussian innovation for most of the data used in this paper, all bootstrap test inferences are drawn from the test with nonparametric resampling method. The bootstrap algorithm for the Granger causality test consists of four steps.

Step 1. Given the original observation, estimate coefficients by the estimated generalized least square (EGLS) method for VAR model (5) under H_0 and H_1, respectively, and obtain the test statistic $\hat{\lambda}$.[1]

$$\hat{\lambda} = T(ln|S_{H_0}| - ln|S_{H_1}|) \tag{6}$$

S_{H_0} and S_{H_1} are residual covariance matrices under H_0 and H_1, respectively.

Step 2. Use the estimates $\hat{\phi}_i$'s under the null hypothesis in step 1 to generate the pseudo-data $\{s_t^*,\ f_t^*\}$ with the same length as the original data $\{s_t,\ f_t\}$. For instance, if the null hypothesis is Δs_t does not Granger causes Δf_t, the DGP is:

$$\begin{aligned} \Delta s_t^* &= \hat{c}_s + \sum_{i=1}^{4} \hat{\phi}_i^{11} \Delta s_{t-i}^* + \sum_{i=1}^{4} \hat{\phi}_i^{12} \Delta f_{t-i}^* + u_{s,t}^* \\ \Delta f_t^* &= \hat{c}_f + \sum_{i=1}^{4} \hat{\phi}_i^{22} \Delta f_{t-i}^* + u_{f,t}^* \end{aligned} \tag{7}$$

To initialize this process, specify $\left(\Delta s_{t-j}^*, \Delta f_{t-j}^*\right)' = (0,0)'$ for $j = 1,\ldots,4$ and discard the first 500 created data. The pseudo innovation term $u_t^* = (u_{s,t}^*, u_{f,t}^*)'$ is random and drawn with replacement from the set of observed residuals $\hat{u}_t = (\hat{u}_{s,t}, \hat{u}_{f,t})'$ obtained from step 1. After repeating this step 2000 times, the

[1] Several standard test statistics, such as the *F* test statistic, the Wald statistic, and the likelihood ratio (*LR*) test statistic, can be used in the bivariate Granger causality test. Since the standard *F*, Wald, and *LR* test statistics are the same asymptotically, this paper provides the test result from the *LR* test statistic.

2000-bootstrapped samples are obtained. [2]

Step 3. For each bootstrapped sample, re-estimate the coefficients in the VAR model (5), and construct the corresponding test statistic $\hat{\lambda}^*$ as in step 1.

$$\hat{\lambda}^* = T(ln|S^*_{H_0}| - ln|S^*_{H_1}|) \tag{8}$$

Step 4. Use the 2000 test statistics $\hat{\lambda}^*$ obtained from the bootstrapped replications in step 3 to construct the empirical distribution and determine the *p*-value for the *LR* statistic $\hat{\lambda}$ of step 1.

4. Empirical Results

Bootstrapping test results are determined by the empirical *p*-value from 2000 bootstrapped samples, and the asymptotic test results are based on the *p*-value of the asymptotic χ^2 distribution. Following Engel and West (2005), the full sample is divided into two sub-samples in 1990:3 due to major economic and noneconomic developments in this period. Tables 1 to 3 summarize *p*-values of the *LR* test statistics of the Granger causality test results from different test methods on each sample period.[3]

Full Sample **(1974:Q1~2001:Q3)**. Tables 1(a) and 1(b) summarize *p*-values of the *LR* test statistic in Granger causality test from the full sample data based on the standard asymptotic distribution and the empirical bootstrap distribution, respectively. Table 1(a) shows that, at the 5% significant level, seven out of thirty null hypotheses that Δs_t fails to Granger cause Δf_t based on the asymptotic distribution are rejected. There are no rejections for Canada and the United Kingdom, and no null hypotheses are rejected in the cases of the output fundamental $\Delta(y_t - y^*_t)$. At the 1% significance level, we reject the null hypothesis in three out of six countries when we investigate the Granger causality relationship running from the exchange rate to the PPP fundamental.The results based on the bootstrap Granger causality test between the exchange rate and the fundamental are reported in Table 1(b). Table 1(b) shows six rejections in thirty tests at the 5% significance level, so the evidence of the causality running from the exchange rate to the fundamental is slightly weaker than what we have seen in Table 1(a).

Early Part of the Sample **(19974:Q1~1990:Q2)**. Table 2 summarizes the test results for the early part of the full sample. As shown in Table 2(a), the asymptotic test result shows more evidence that the exchange rate Granger causes the fundamental than the full sample. In Table 2(a), the null that Δs_t fails to Granger cause Δf_t is rejected in ten cases at the 5% significance level and in three more cases at the 10% significance level. For the output

---

[2] This study refers to Davidson and MacKinnon (2000), choosing to bootstrap 2000 replications because the bootstrapping *p*-value of the test statistic $\hat{\lambda}$ constructed from 2000 replications differed only marginally from those constructed from 2500 or 5000 replications.

[3] The asymptotic test in this paper is replication results of Engel and West's Granger causality test.

fundamental $\Delta(y_t - y_t^*)$, which we do not see any result showing that Δs_t causes Δf_t in the full sample, but one rejection is found in the early part of sample period for Japan.

However, the bootstrap test results in Table 2(b) are very different from Table 2(a). The evidence of the Granger causality relationship running from exchange rates to fundamentals is weaker in the bootstrap test than in the asymptotic test. At the 5% significance level, only three cases of the null of no Granger causality are rejected, and no rejections are found in the cases of the output fundamental $\Delta(y_t - y_t^*)$.

Later Part of the Sample **(1990:Q3~2001:Q3)**. Table 3 reports the test results for the later part of the full sample. In Table 3(a), the evidence that the exchange rate Granger causes the fundamental is statistically significant. The null hypotheses of no-Granger-causality from exchange rates to fundamentals are rejected in nine cases at the 5% significance level and five more cases at the 10% significance level. However, as illustrated in Table 3(b), the rejection frequency to the no-Granger-causality null hypothesis is much less based on the bootstrap distribution than based on the asymptotic distribution. The null hypothesis that Δs_t fails to cause Δf_t is rejected in only two cases at the 5% significance level, and three more cases at the 10% significance level. Moreover, only one of the null that Δf_t fails to cause Δs_t is rejected.

To summarize, when implementing the test with the smaller sample, the evidence of the Granger causality based on the bootstrap method is very weak. For the full sample, the evidence of the Granger causality relationship between exchange rates and fundamentals from the bootstrap test is slightly weaker than the asymptotic test's. However, the results of the bootstrap test with the later part of the sample are greatly different from the results of the asymptotic test. Little evidence that exchange rates Granger cause fundamentals is found in the bootstrap test. This suggests that the Granger causality relationship between exchange rates and fundamentals is not as significant as what Engel and West (2005) have discovered. Therefore, the reliability of positive evidence that Engel and West (2005) found for the present-value model is greatly discounted.

5. Size of the Tests

In the previous section, we find that results of the Granger causality test from exchange rates to fundamentals based on two different test approaches are distinct when using small samples. Although it is well-known that the asymptotic test statistics constructed from the small sample data suffer from the size distortion, it is not sufficient to draw the conclusion that the evidence from the bootstrap test is more convincing than the asymptotic test. In this section, we test the robustness of the two test methods and examine whether the bootstrap test performs better than the asymptotic test in this particular application.

For the size test, the parameters for the Monte Carlo DGPs are estimated from the real data with the restriction of the null hypothesis. Under the null that Δs_t does not Granger cause Δf_t, the pseudo time-series sequence of $\left(\Delta s_t^{\dagger}, \Delta f_t^{\dagger}\right)'$ in a trial of the experiment is generated by:

$$\begin{aligned} \Delta s_t^{\dagger} &= \hat{c}_s + \sum_{i=1}^{4} \hat{\phi}_i^{11} \Delta s_{t-i}^{\dagger} + \sum_{i=1}^{4} \hat{\phi}_i^{12} \Delta f_{t-i}^{\dagger} + u_{s,t}^{\dagger} \\ \Delta f_t^{\dagger} &= \hat{c}_f + \sum_{i=1}^{4} \hat{\phi}_i^{22} \Delta f_{t-i}^{\dagger} + u_{f,t}^{\dagger} \end{aligned} \tag{9}$$

The regression coefficients $\hat{c}_s, \hat{c}_f, \hat{\phi}_i^{11}, \hat{\phi}_i^{12}$ and $\hat{\phi}_i^{22}$, $i = 1, \cdots, 4$, are estimated from the observed data with the EGLS method. The innovation term in the Monte Carlo experiment $u_t^{\dagger} = (u_{s,t}^{\dagger}, f_{f,t}^{\dagger})'$ is randomly drawn from the observed EGLS residuals. For each trial of the Monte Carlo experiment, we use the parameter estimates to simulate the pseudo data for the Granger causality test. Effective size of the asymptotic and the bootstrap test is determined by the nominal 10% test with 1000 trials of the Monte Carlo experiment. For the bootstrap Granger causality test, the algorithm is the same as illustrated in Section 3.

The size of the 10% test is tabulated in Figures 1 to 3. The upper panel of the figures summarizes the size of the asymptotic tests, and the lower panel of figures summarizes the size of the bootstrap tests. Since the nominal size of the test is 10%, the ideal value of size of a test is 0.1. We see that, in the upper panel of Figure 1, the size of the asymptotic test is slightly larger than 10%. For the early part of the sample, as the upper panel of Figure 2 displays, size of the asymptotic test increases by a large percentage. For the later part of the sample, the upper panel of Figure 3 shows that size of the asymptotic test raises in all fundamental measures and in all sample countries by a large percentage. Moreover, some magnitudes of the size of the asymptotic test rise up to almost 40%.

In contrast, as what can be seen in the lower panels of Figure 1 to Figure 3, the size of the bootstrap test does not change much and remains stable at the nominal 10% significance level. Also, the size of the bootstrap test is lower than that of the asymptotic test in all samples. The results show that the bootstrap test has less size distortion in this particular application.

Therefore, the Monte Carlo study shows large size in the asymptotic test, which implies that the asymptotic Granger causality test suffers the size distortion problem for the type of the data used in Engel and West's (2005) study. It is not surprising to see statistically significant evidence of the Granger causality running from exchange rates to fundamentals in Engle and West's study.

6. Conclusion

This study is in response to the finding of the Granger causality relationship based on the asymptotic test in Engel and West (2005). In Engel and West's study, the authors use the present-value model to explain the finding of the close to random walk exchange rate in empirical studies. Although the empirical findings of the near-random walk exchange rate are consistent with the exchange rate behavior under their explanation, the findings are not sufficient to directly confirm the present-value model for exchange rates. The Granger causality test with the asymptotic method is implemented to validate the model. However, the type of data used in their study is very likely to lead to the size distortion in the test results because the sample size of the data is small.

This paper employs the bootstrap method to re-evaluate the evidence of the causality relationship between exchange rates and fundamentals. The bootstrap test results show that the evidence of Granger causality from exchange rates to fundamentals is not as significant as the existing evidence from the asymptotic method in all sample periods. Additionally, the Monte Carlo experiment results show that the bootstrap test performs better than the asymptotic test in respect of the robustness of the tests in this particular application. The large size in the asymptotic test shows that Engel and West's results are greatly distorted by the small-sample problem. Therefore, the existing Granger causality evidence is not strong enough to support the present-value model for exchange rate under Engel and West's explanation.

More direct evidence is needed for the present-value model for exchange rates. One may explore long-horizon exchange rate predictability under the present-value model. For example, over the longer horizon, the near-one discount rate factor becomes smaller, so one of Engel and West's assumptions for the near random walk exchange rate fails. In addition, if the unobservable fundamentals are not $I(1)$, the long-horizon regression may have predictability power for exchange rate (Engel, Wang, and Wu, 2009).

References

Andrews, Donald W. K. and Moshe Buchinsky. 2000. "A Three-step Method for Choosing the Number of Bootstrap Repetitions." *Econometrica* 68 (1): 23-51.

Ashley, Richard, Clive W. J. Granger , and Richard Schmalensee. 1980. "Advertising and Aggregate Consumption: An Analysis of Causality." *Econometrica* 48 (5): 1149-67.

Berkowitz, Jeremy and Lutz Kilian. 2000. "Recent Developments in Bootstrapping Time Series." *Econometric Reviews* 19 (1): 1-48.

Campbell, John Y. Campbell and Robert J. Shiller. 1987. "Cointegration and Tests of Present Value Models." *The Journal of Political Economy* 95 (5): 1062-88.

Cheung, Yin-Wong, Menzie D. Chinn and Antonio G. Pascual. 2005. "Empirical Exchange Rate Models of the Nineties: Are Any Fit to Survive?" *Journal of International Money and Finance* 24 (7): 1150-75.

Davidson, Russell and James G. MacKinnon. 2000. “Bootstrap Tests: How Many Bootstraps?” *Econometric Reviews* 19 (1): 55-68.

Efron, Bradley and Robert Tibshirani. 1993. *An Introduction to the Bootstrap*. New York, NY, Chapman & Hall.

Engel, Charles, Jian Wang and Jason Wu. 2010. “Long-Horizon Forecasts of Asset Prices when the Discount Rate is Close to Unity.” Working paper, University of Wisconsin, Madison.

Engel, Charles and Kenneth D. West. 2005. “Exchange Rate and Fundamentals.” *Journal of Political Economy* 113 (3): 485-517.

Faust, Jon, John H. Rogers, and Jonathan H. Wright. 2003. “Exchange Rate Forecasting: the Errors We've Really Made.” *Journal of International Economics* 60 (1): 35-59.

Frenkel, Jacob A. 1976. “A Monetary Approach to the Exchange Rate: Doctrinal Aspects and Empirical Evidence.” *Scandinavian Journal of Economics* 78 (2): 200-24.

______. 1979. “On the Mark: A Theory of Floating Exchange Rates Based on Real Interest Differentials.” *The American Economic Review* 69 (4): 610-22.

Granger, Clive W. J. 1969. “Investigating Causal Relations by Econometric Models and Cross-spectral Methods.” *Econometrica* 37 (3): 424-38.

Peter Hall. (1986). “On the Number of Bootstrap Simulations Required to Construct a Confidence Interval.” *The Annals of Statistics* 14 (4): 1453-62.

Kilian, Lutz. 1999. “Exchange Rates and Monetary Fundamentals: What Do We Learn from Long-Horizon Regressions?” *Journal of Applied Econometrics* 14 (5): 491-510.

Li, G. S. Hongyi and Maddala. 1996. “Bootstrapping Time Series Models.” *Econometric Reviews* 15 (2): 115-58.

______. 1997. “Bootstrapping Cointegrating Regressions.” *Journal of Econometrics* 80 (2): 297-18.

Ma, Yue and Angelos Kanas. 2000. “Testing for Nonlinear Granger Causality from Fundamentals to Exchange Rates in the ERM.” *Journal of International Financial Markets, Institutions and Money* 10 (1): 69-82.

_______. 2000. “Testing for a nonlinear relationship among fundamentals and exchange rates in the ERM” *Journal of International Money and Finance* 19 (1): 135-52

Mark, Nelson C. 1995. “Exchange Rates and Fundamentals: Evidence on Long-Horizon Predictability.” *The American Economic Review* 85 (1): 201-18.

Mark, Nelson C. and Donggyu Sul. 2001. “Nominal exchange rates and monetary fundamentals: Evidence from a small post-Bretton woods panel.” *Journal of International Economics* 53 (1): 29-52.

Meese, Richard A., and Kenneth Rogoff. 1983a. “Empirical Exchange Rate Models of the Seventies: Do They Fit Out of Sample?” *Journal of International Economics* 14 (1-2): 3-24.

_______. 1983b. “The Out of Sample Failure of Empirical Exchange Rate Models” in Jacob A. Frenkel, ed., *Exchange Rates and International Macroeconomics*. Chicago, IL: University of Chicago Press, pp. 6-105

Obstfeld, Maurice, and Kenneth Rogoff. 2000. “The Six Major Puzzles in International Macroeconomics: Is There a Common Cause?” *NBER Macroeconomics Annual* 15, 339-90.

Table 1

Bivariate Granger Causality Test Results- Full Sample: 1974:1-2001:3

(a) p-values for the Asymptotic Test Statistics

	Canada	France	Germany	Italy	Japan	United Kingdom
	A. Rejections at 1%(**), 5%(*), and 10%(†) Levels of H$_0$: Δs_t Fails to Cause Δf_t					
1.$\Delta(m_t - m_t^*)$	0.1660	0.0668†	0.6117	0.0367*	0.0177*	0.3544
2.$\Delta(p_t - p_t^*)$	0.9324	0.1118	0.0079**	0.0023**	0.0092**	0.5522
3.$\Delta(i_t - i_t^*)$	0.3834	0.0156*	0.2674	0.5608	0.0019**	0.1165
4. $\Delta(m_t - m_t^*) - \Delta(y_t - y_t^*)$	0.2287	0.0775†	0.7873	0.0587†	0.1155	0.4876
5.$\Delta(y_t - y_t^*)$	0.1125	0.6602	0.9628	0.7882	0.6698	0.5153

(b) p-values for the Bootstrap Test Statistics

	Canada	France	Germany	Italy	Japan	United Kingdom
	A. Rejections at 1%(**), 5%(*), and 10%(†) Levels of H$_0$: Δs_t Fails to Cause Δf_t					
1.$\Delta(m_t - m_t^*)$	0.1915	0.1110	0.6665	0.0605†	0.0360*	0.3965
2.$\Delta(p_t - p_t^*)$	0.9350	0.1530	0.0150*	0.0040**	0.0145*	0.5960
3.$\Delta(i_t - i_t^*)$	0.4115	0.0235*	0.3230	0.6080	0.0045**	0.1595
4. $\Delta(m_t - m_t^*) - \Delta(y_t - y_t^*)$	0.2610	0.1280	0.8275	0.0940†	0.1625	0.5365
5.$\Delta(y_t - y_t^*)$	0.1420	0.7050	0.9675	0.8215	0.7120	0.5745

Table 2

Bivariate Granger Causality Test Results - Early Part of the Sample: 1974:1-1990:2

(a) *p*-values for the Asymptotic Test Statistics

	Canada	France	Germany	Italy	Japan	United Kingdom
	A. Rejections at 1%(**), 5%(*), and 10%(†) Levels of H$_0$: Δs_t Fails to Cause Δf_t					
1.$\Delta(m_t - m_t^*)$	0.2239	0.0333*	0.2925	0.0681†	0.1361	0.5791
2.$\Delta(p_t - p_t^*)$	0.3897	0.0689†	0.0252*	0.0006**	0.0264*	0.4531
3.$\Delta(i_t - i_t^*)$	0.4452	0.0059**	0.2621	0.6619	0.0159*	0.0374*
4.$\Delta(m_t - m_t^*) - \Delta(y_t - y_t^*)$	0.6016	0.0285*	0.3325	0.0286*	0.0935†	0.8211
5.$\Delta(y_t - y_t^*)$	0.4333	0.7379	0.9163	0.6215	0.0353*	0.7031

(b) *p*-values for the Bootstrap Test Statistics

	Canada	France	Germany	Italy	Japan	United Kingdom
	A. Rejections at 1%(***), 5%(**), and 10%(†) Levels of H$_0$: Δs_t Fails to CauseΔf_t					
1.$\Delta(m_t - m_t^*)$	0.2930	0.0860†	0.3865	0.1405	0.2140	0.6750
2.$\Delta(p_t - p_t^*)$	0.4770	0.1195	0.0500*	0.0035**	0.0595†	0.5370
3.$\Delta(i_t - i_t^*)$	0.5220	0.0125*	0.3355	0.7420	0.0575†	0.0680†
4.$\Delta(m_t - m_t^*) - \Delta(y_t - y_t^*)$	0.6580	0.0800*	0.4270	0.0575†	0.1555	0.8525
5.$\Delta(y_t - y_t^*)$	0.5255	0.8005	0.9400	0.6960	0.0615	0.7615

Table 3

Bivariate Granger Causality Test Results - Later Part of the Sample: 1990:3-2001:3

(a) p-values for the Asymptotic Test Statistics

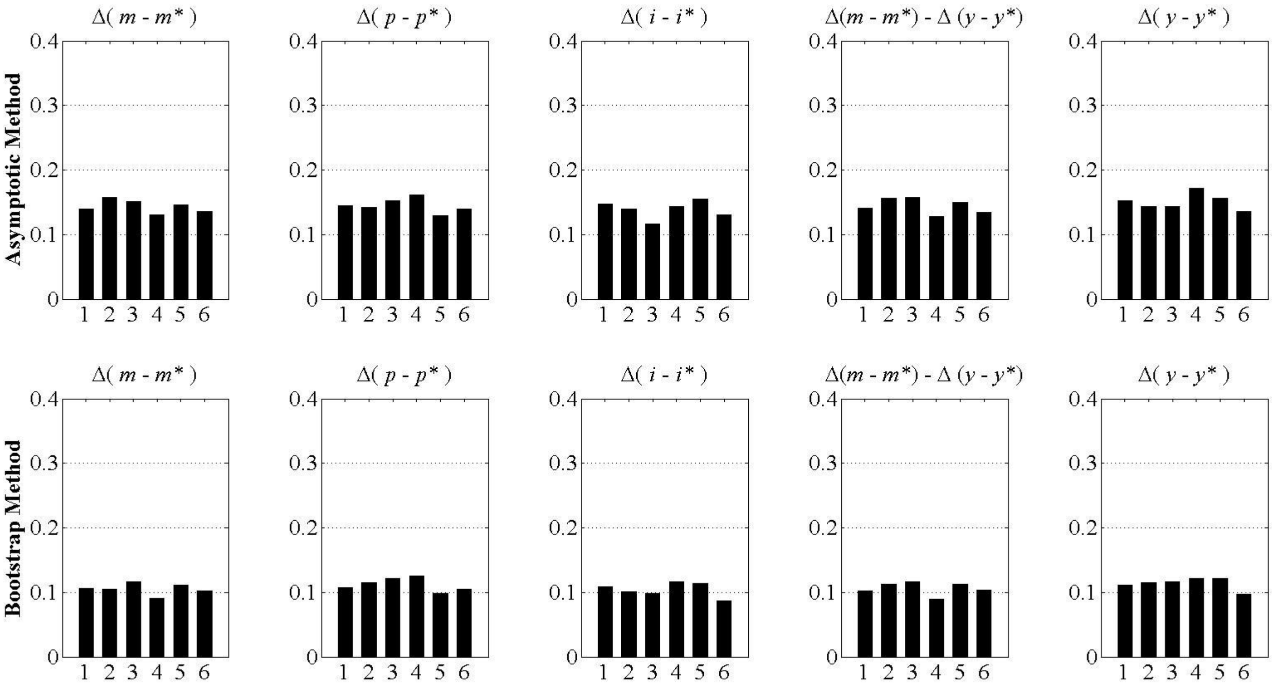
	Canada	France	Germany	Italy	Japan	United Kingdom
	A. Rejections at 1%(**), 5%(*), and 10%(†) Levels of H$_0$: Δs_t Fails to Cause Δf_t					
1.$\Delta(m_t - m_t^*)$	0.0226*	0.0627†	0.8818	0.3189	0.0344*	0.2139
2.$\Delta(p_t - p_t^*)$	0.0583†	0.0172*	0.0001**	0.1646	0.3490	0.0988†
3.$\Delta(i_t - i_t^*)$	0.1646	0.5221	0.0462*	0.0453*	0.0627†	0.5340
4.$\Delta(m_t - m_t^*) - \Delta(y_t - y_t^*)$	0.0039**	0.0202*	0.4830	0.6224	0.5327	0.0546†
5.$\Delta(y_t - y_t^*)$	0.1094	0.2003	0.6515	0.2781	0.3139	0.0217*

(b) p-values for the Bootstrap Test Statistics

	Canada	France	Germany	Italy	Japan	United Kingdom
	A. Rejections at 1%(**), 5%(*), and 10%(†) Levels of H$_0$: Δs_t Fails to Cause Δf_t					
1.$\Delta(m_t - m_t^*)$	0.0745†	0.2145	0.9420	0.5620	0.1120	0.3630
2.$\Delta(p_t - p_t^*)$	0.1685	0.0705†	0.0025**	0.2855	0.5175	0.2095
3.$\Delta(i_t - i_t^*)$	0.3105	0.6940	0.1365	0.1165	0.1675	0.6640
4.$\Delta(m_t - m_t^*) - \Delta(y_t - y_t^*)$	0.0245**	0.1205	0.7100	0.7835	0.6780	0.1345
5.$\Delta(\mathrm{y}_t - \mathrm{y}_t^*)$	0.2310	0.3605	0.7620	0.4305	0.4880	0.0665†

Figure 1

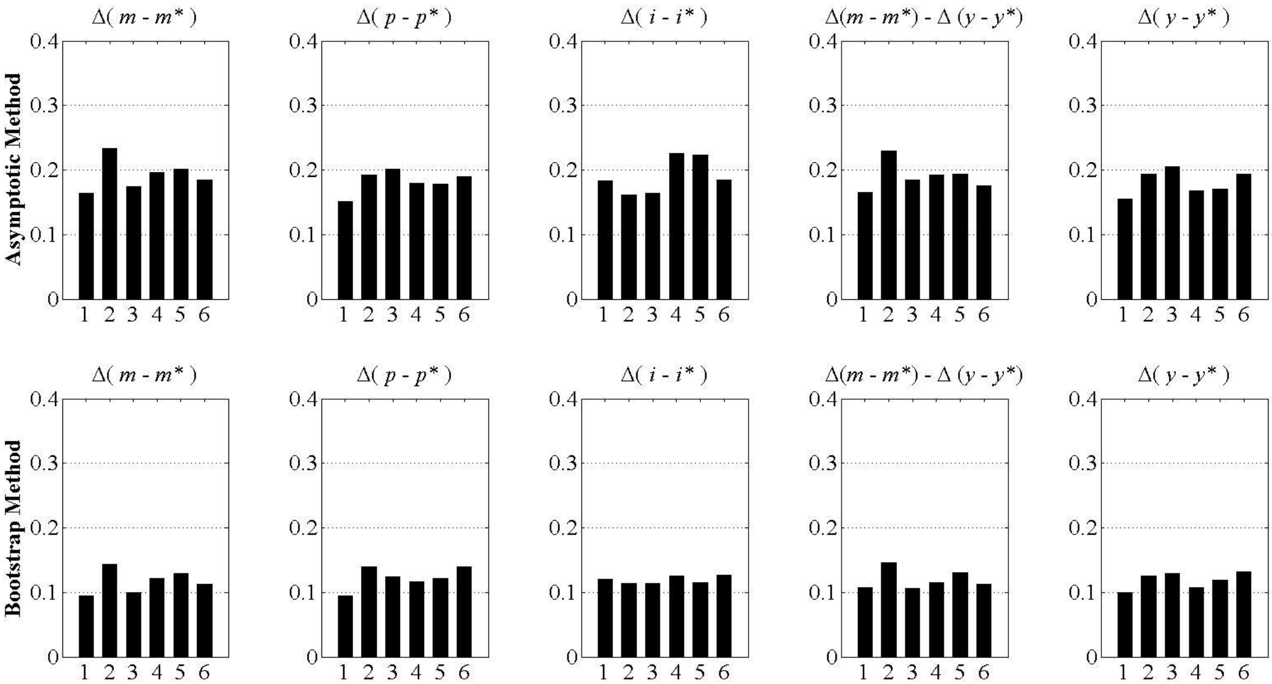
Size of the Test- Full Sample (1974:1-2001:3)



NOTE.— Number 1 to 6 represents Canada, France, Germany, Italy, Japan, and the United Kingdom, respectively.

Figure 2

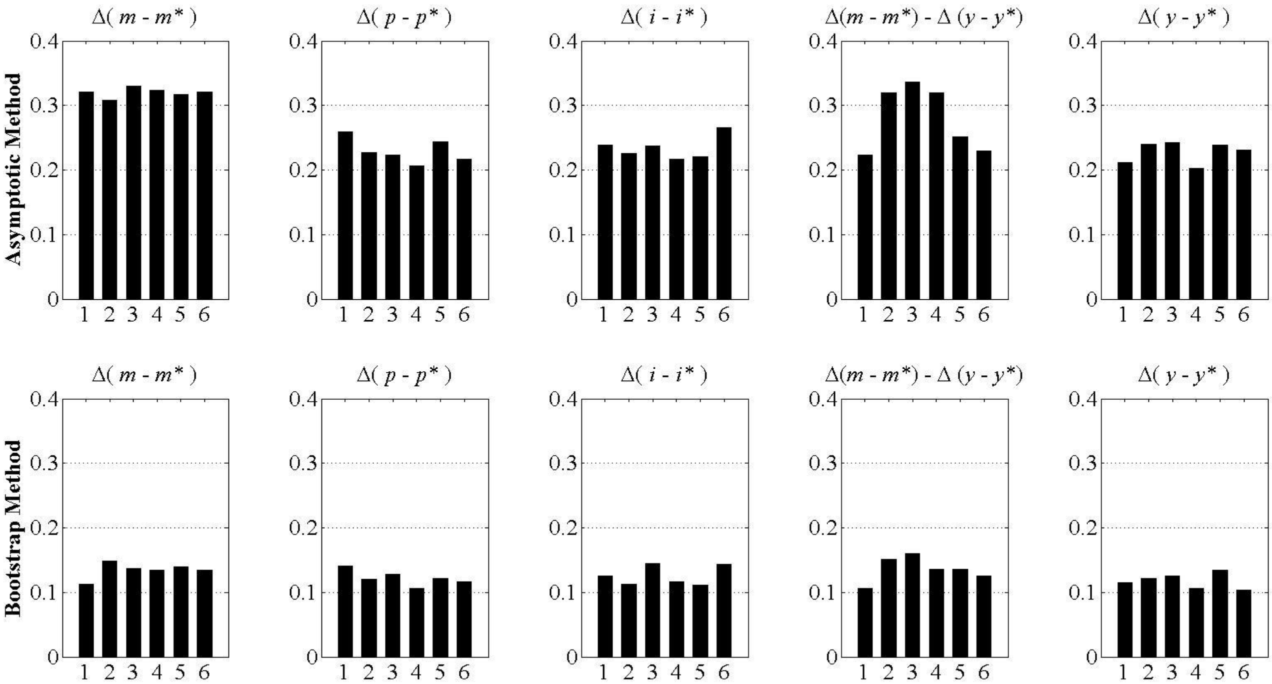
Size of the Test- Early Part of the Sample (1974:1-1990:2)



NOTE.— Number 1 to 6 represents Canada, France, Germany, Italy, Japan, and the United Kingdom, respectively.

Figure 3

Size of the Test- Later Part of the Sample (1990:3-2001:3)



NOTE.— Number 1 to 6 represents Canada, France, Germany, Italy, Japan, and the United Kingdom, respectively.