Testing efficient market hypothesis for the dollar–sterling gold standard exchange rate 1890–1906: MLE with double truncation

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Abstract

This paper tests an efficient market hypothesis for the dollar–sterling exchange rate under the classical gold standard in the period 1890–1906. The test is based on maximum likelihood estimation of doubly truncated time series. The results show that weak-form efficiency cannot be rejected if truncation by the gold points is incorporated. The results, however, are sensitive to the gold points estimates used. © 2000 Elsevier Science S.A. All rights reserved.

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JEL classification: C2; N2.

1. Introduction

Many authors examined whether the classical gold standard system in the late 19th and early 20th century in the U.S. and the U.K. was efficient: some of the authors supported the case for efficiency while others refuted it. The majority of these studies focus on the gold point violations by the exchange rates rather than directly testing an efficient market hypothesis.

In this paper we test the weak form of the efficient market hypothesis by a maximum likelihood estimation procedure incorporating the gold points. The efficient market hypothesis implies that the players in the market will use available information fully. As Officer (1989, 1996) puts it, when the exchange rate is at or beyond a gold point, gold arbitrageurs and speculators will transact to turn the

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exchange rate away from the gold points. Econometrically, if the exchange rates were bounded by the gold points, the estimation of the key time series coefficient, i.e. the random walk parameter, would be biased if the bounds are ignored. A proof of downward bias is given in Tsurumi (1998).

The results we obtain for the period 1890–1906 are that the unit root cannot be rejected when we incorporate the gold points, while ignoring them leads to the rejection of the unit root, and thus the rejection of the weak form of market efficiency. We also show that the unit root test is sensitive to the estimates of the gold points. We concur with the consensus in the literature that the efficiency of the dollar–sterling gold standard depends on the estimates of the gold points.

The organization of the paper is as follows. In section 2 we summarize the results of the representative studies. In section 3 we present the estimated results.

2. Summary of findings in the literature

Although there are many studies of the efficiency of the gold standard system, it may be safe to say the studies by Morgenstern (1959), Clark (1984), Officer (1989, 1996), Prakash and Taylor (1997), and Hallwood et al. (1996) are representative.

Both Morgenstern (1959) and Clark (1984) found many persistent gold point violations and hence concluded that the gold standard was inefficient. Officer (1989, 1996) first estimated the gold points taking into account various components of transaction costs and interest rates. He finds much fewer violations of the gold points than his predecessors. Officer (1989, 1996) argues that because of the joint arbitrage and speculation activities the gold standard was “remarkably efficient” in the period 1890–1906 with the exchange rate not only staying within the gold points but also being concentrated around the middle of the band.1

Prakash and Taylor (1997) use the threshold autoregression (TAR) model allowing for three regimes: exchange rate above the gold export point, exchange rate within the spread, and exchange rate below the gold import point. Using daily exchange rate data they estimate the gold point spread as well as the parameters of the AR(1) process in each regime. They assume that within the gold points the exchange rate follows a random walk. Their estimates of the gold points are much narrower than Officer’s, and they explain that the difference is due to their use of pure arbitrage model, which does not include speculation.

Hallwood et al. (1996) suggest a target zone model where speculators intervene at the edges of the band, so the expected change of the exchange rate within the band will be mean reverting. They provide the variance ratio and ADF tests of a unit root and conclude that the process is stationary within the bands. They do not take into consideration the upper and lower bounds (i.e. gold export and gold import points) in carrying out the unit root tests.

1 Officer uses a loss function to evaluate the efficiency. In the simplest case the loss function is the sum of percentage absolute value deviations of the exchange rate from the midpoint of the gold points. This loss is compared to one for the uniform distribution of exchange rate, which assumes perfect arbitrage and neutral speculation. The ratio of the two loss functions turns out to be less than one, leading to the conclusion that the regime is efficient.
3. Testing the weak form of market efficiency

A conventional definition of an efficient market is given in Fama (1970) as a market in which prices always “fully reflect” available information. The definition of weak-form efficiency is given in Campbell et al. (1997); the information set includes only the history of prices or returns themselves. The weak-form efficiency hypothesis implies that prices follow a martingale process:

\[ E[P_{t+1} | \mathcal{F}_t] = P_t, \mathcal{F}_t \]

where \( \mathcal{F}_t \) is the information set available up to time \( t \).

To test the weak form efficiency hypothesis, let \( y_t \) be the exchange rate at time \( t \) given by

\[ y_t = p y_{t-1} + \varepsilon_t \]  

(1)

where \( \varepsilon_t \) is a stationary Gaussian process with mean zero. The weak form efficiency hypothesis is given as the null hypothesis: \( H_0 : p = 1 \) against the alternative hypothesis \( H_1 : |p| < 1 \). If the exchange rates are bounded by the gold points, then \( \{y_t\} \) follows

\[ a_t \leq y_t \leq b_t \]  

(2)

where \( a_t \) and \( b_t \) are, respectively, the gold export and import points at time \( t \). In Appendix A we present the maximum likelihood procedure.

We use monthly spot exchange rate data for the period 1890–1906 from Obstfeld and Taylor (1997) \(^2\) and the estimates of the gold points from Officer (1996) in order to perform the MLE with double truncation. As discussed in Cole (1929) and Morgenstern (1959), seasonal adjustment needs to be taken care of, thus three dummy variables were added into model (1). \(^3\) Fig. 1 shows the monthly exchange rates and Officer’s gold points estimates. Following Officer we consider percentage deviations of the exchange rate from the mint parity, and the gold points are also expressed in percentage deviations from parity.

The advantage of using this exchange rate data is that many historical studies of that period indicate that arbitrageurs mostly used demand bills (sight rates) of exchange in sterling drawn on London. The disadvantage is that data is averaged over the month and rounded. We also use NBER data of London exchange rates on New York expressed as $/pound. These data were originally used by Morgenstern (1959) and are presented in Fig. 2.

Looking at Figs. 1 and 2 we observe relatively stable fluctuations of the exchange rates. The maximum deviation from parity is about 1.5% and occurs in the currency crisis of 1895 when a speculative attack on the dollar by market agents, fearing the U.S. would leave gold standard was repelled by a rescue organized by August Belmont and J.P. Morgan (see Friedman and Schwartz (1963)). Most of the deviations are within 0.5%. There are a few violations of the gold export and gold import points, but they are not persistent. The gold points become narrower over time reflecting decreasing transportation and other components of the costs of shipping gold. The likelihood function

\(^2\)These data were originally collected from the Commercial and Financial Chronicle.

\(^3\)Preliminary data processing led us to introduce seasonal dummy variables in the regression rather than the stochastic seasonality of an ARMA process. With the introduction of the seasonal dummies, the error process \( \{\varepsilon_t\} \) is judged to be white noise, and thus \( \{\varepsilon_t\} \) is specified as the Gaussian white noise process.
(A.1) in Appendix A should be modified to take into account observations outside the band (violations). For such points the probability in the likelihood is considered to be the same as without truncation. Results of the estimation of $\rho$, $\sigma$ and seasonal dummy variables for the period 1890–1906 (204 observations) are given in Tables 1 and 2 for the two exchange rate data sets.

Sources: Exchange rates from Obstfeld and Taylor (1997); Gold points: Officer (1996).

Fig. 1. Exchange rate and gold points New York: monthly 1890–1906.

Sources: Exchange rates from NBER. Gold points from Officer (1996).

Fig. 2. Exchange rate and gold points. London on New York: monthly 1890–1906.
Table 1
MLE estimation of monthly rates of exchange in New York, 1890–1906

<table>
<thead>
<tr>
<th></th>
<th>With truncation</th>
<th>Ignoring truncation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLE of $\rho$</td>
<td>1.0222 (0.0814)$^a$</td>
<td>0.7362 (0.0515)</td>
</tr>
<tr>
<td>MLE of $\sigma$</td>
<td>0.2886</td>
<td>0.2372</td>
</tr>
<tr>
<td>MLE of seasonal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dummy variables</td>
<td>0.0706 (0.0775)</td>
<td>0.1146 (0.0369)</td>
</tr>
<tr>
<td></td>
<td>−0.0993 (0.0883)</td>
<td>−0.0821 (0.0354)</td>
</tr>
<tr>
<td></td>
<td>−0.1090 (0.0785)</td>
<td>0.0432 (0.0332)</td>
</tr>
</tbody>
</table>

$^a$ Standard errors are given in brackets.

From the tables we see that there is a difference between the MLE of $\rho$ with truncation and ignoring truncation: the estimator of $\rho$ that ignores truncation is biased to the left, as we expected from Tsurumi (1998). A simple unit root test ignoring truncation will tend to reject a unit root toward a stationary process and this would lead to the wrong conclusion of a stationary process ($\rho < 1$) for the period 1890–1906. In fact, the process only seems to be stationary due to the restriction of the gold points. If truncation is taken into account the unit root hypothesis cannot be rejected at the 5% significance level for 1890–1906, a period which Officer considered to be “remarkably efficient”. Moreover, the result is robust for both exchange rate data sets: on New York market and on the London market.$^4$

It is worth pointing out that the unit root test is sensitive to the gold points estimates used as upper and lower bounds. The narrower is the band (the lower are the estimates of the transactions costs of arbitrage), the more likely that we do not reject the unit root. Had we used narrower gold points estimates (like those used by Clark et al.), we might not reject a unit root process for other periods during the classical gold standard as well.$^5$ So, the results of doubly-truncated estimation depend on the gold-points estimates.

Table 2
MLE estimation of monthly London rates of exchange on New York, 1890–1906

<table>
<thead>
<tr>
<th></th>
<th>With truncation</th>
<th>Ignoring truncation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MLE of $\rho$</td>
<td>1.0455 (0.0859)$^a$</td>
<td>0.7309 (0.0514)</td>
</tr>
<tr>
<td>MLE of $\sigma$</td>
<td>0.2440</td>
<td>0.2174</td>
</tr>
<tr>
<td>MLE of seasonal</td>
<td></td>
<td></td>
</tr>
<tr>
<td>dummy variables</td>
<td>0.976 (0.0623)</td>
<td>0.0842 (0.0325)</td>
</tr>
<tr>
<td></td>
<td>0.0018 (0.0704)</td>
<td>−0.0509 (0.0322)</td>
</tr>
<tr>
<td></td>
<td>−0.0967 (0.0618)</td>
<td>0.0052 (0.0306)</td>
</tr>
</tbody>
</table>

$^a$ Standard errors are given in brackets.

$^4$ Another important result is that $\sigma$ is smaller for the 1890–1906 period than in the preceding period (1879–1889). This indicates that exchange rate was also stable in the period of “remarkable efficiency”.

$^5$ With Officer’s gold points we reject weak-form efficiency for the period 1907–1914. When we performed such tests making upper and lower bounds equal to the maximum and minimum observations the result was that unit root can not be rejected at the 5% significance level.
It is well known that the classical gold standard regime was extremely credible, meaning that speculators and other agents believed in the government’s ability to protect the fixed parity regime. Arbitrageurs and speculators acted as if they knew the gold points. Thus, the market exchange rate stayed mostly within the bounds, or returned inside the bounds after a violation, quickly eliminating positive profit opportunities from arbitrage. Officer’s conclusion of a “remarkably efficient” gold standard between 1890 and 1906 and widely excepted view in literature of the efficient classical gold standard is confirmed by our estimate of unit root incorporating double truncation. The debate in literature about the estimates of gold points is very important since the conclusion of efficient gold standard is sensitive to the bounds of double truncation for exchange rate.

Acknowledgements

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Appendix A

Consider a model of random walk under exogenous double truncation:

\[ y_t = \rho y_{t-1} + \epsilon_t, \quad \rho = 1 \]

\[ a_t \leq y_t \leq b_t \]

\[ y_0 = 0 \]

\[ \epsilon_t \sim N(0, \sigma^2) \]

Maximum likelihood estimation.

The maximum likelihood estimators of \( \rho \) and \( \sigma \) in model (1) we can get from maximization of the likelihood function

\[ L = \prod_{t=1}^{n} \frac{1}{\sigma} \phi \left( \frac{y_t - \rho y_{t-1}}{\sigma} \right) \]

\[ \frac{1}{\sigma} \left( \phi \left( \frac{b_t - \rho y_{t-1}}{\sigma} \right) - \phi \left( \frac{a_t - \rho y_{t-1}}{\sigma} \right) \right) \]  (A.1)

where \( \phi(\cdot) \) and \( \Phi(\cdot) \) are respectively, the probability density function and distribution function of the standardized normal variable.

\(^6\)However, we know that authorities occasionally followed ‘gold policies’ to influence the gold points as a way to protect the gold reserves in the face of an outflow. For example, they could charge an additional premium to purchase gold at the mint. These facts suggest that the gold points may become endogenous rather than exogenous at certain times. If we knew the exact dates of such interventions, which we do not, we could account for this effect in our estimation.

\(^7\)The model can be generalized to random walk with drift.
**Theorem.** If \( a \) and \( b \) follow an exogenous truncation process the MLE estimator \( \hat{\phi}_{\text{MLE}} \) is consistent and \( \sqrt{n}(\hat{\phi}_{\text{MLE}} - 1) \rightarrow N(0,\Omega) \) normal distribution with zero expectation and finite variance.

**Remark.** The theorem says with the double truncation of \( y_t \) in \( (1) \), \( n(\hat{\phi}_{\text{MLE}} - 1) \) does not converge to the ratio of functions of Brownian motion. \( \sqrt{n}(\hat{\phi}_{\text{MLE}} - 1) \) converges to a normal variable.

**References**


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\(^8\text{Proof can be obtained from the author.}\)