Economica, **46,** 261–279

The Relationship between Interest Rates and Gold Flows under the Gold Standard: A New Empirical Approach

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Introduction

Forty years have passed since the appearance of P. Barrett Whale's well known article, "The Working of the Pre-War Gold Standard" (1937). In seeking to explain exactly how the prewar gold standard functioned, Whale criticized the classical view and the view of the banking school. As an alternative explanation, he offered his own view, which emphasized adjustment through changes in income. For all its persuasiveness, his discussion did not resolve the gold standard question, and Whale himself recognized that a fully satisfactory answer could come only from "exhaustive testing". In the last 40 years, empirical treatments of the gold standard problem have been offered by A. I. Bloomfield (1959), O. Morgenstern (1959), A. G. Ford (1962), C. A. E. Goodhart (1972), and McCloskey and Zecher (1976), yet the problem remains unresolved. Of these various studies, only those of McCloskey and Zecher and Goodhart employ current econometric methods. Use of annual data prevents McCloskey and Zecher from exploring the discrete timing of gold standard adjustment. The provocative work of Goodhart, which concentrates on Britain, does not deal adequately with the dynamics of adjustment, and provides no empirical analysis of events elsewhere.

These and other efforts to explain the working of the gold standard have included theories emphasizing price adjustment, income adjustment, and the monetary theory of the balance of payments. (A concise discussion of these theories is given in McCloskey and Zecher, 1976.) It has also been suggested that monetary authorities altered interest rates in a manner that influenced the adjustment process.[1] Although it would be desirable to test each of these theories separately, lack of data or inappropriate periodization of available data precludes such testing. What the data do allow is an examination of a relationship relevant to all of these theories: that between interest rates and gold flows. The relevance of this relationship is easily seen when one recalls that the major effect of discount rates is to attract short-term balances to one financial centre to obtain higher interest return than that offered in other centres. If one believes that adjustment occurs via income adjustment, then one could hold either that discount rates operate directly on the level of economic activity and influence gold flows indirectly through the trade balance, or that discount rate changes are required to control gold movements while longer-term forces of adjustment take place. It has also been argued that interest rates operated on gold flows through changes in domestic prices so that the trade balance was altered by a change in the terms of trade. Another version of the price adjustment argument holds that an increase in the discount rate causes a liquidation of inventory holdings of exportables and imports as a consequence of a change in the costs of financing them, resulting in a temporary improvement in the trade balance. In the context of an argument based on the monetary approach to the balance of payments in which "flows of gold represented the routine satisfaction of demands for money", gold flows also respond to changes in interest rates, although these flows respond to the rate of change of income as well (McCloskey and Zecher, 1976, p. 385). Clearly, further empirical work dealing with the relationship between gold flows and interest under the gold standard is needed.

Whale's analysis of this facet of the adjustment process (as it relates to capital movements) appears in Section V of his 1937 article (pp. 28–31). At the core of this process is the means by which spending power is redistributed. In Whale's view countries having adequate gold reserves can merely allow gold to flow out. The more interesting case is that of countries whose gold reserves are very limited. Here, Whale points out, a troublesome sequence of events may occur:

> if the gold movement necessitates multiple contraction of credit in order to preserve the minimum reserve ratio in the lending country (accompanied perhaps by a multiple expansion of credit in the borrowing country), several complications arise. The change in money supplies will be excessive: interest rates will be distorted to bring about the credit changes: and the changes in interest rates will impede the international movement of capital. In some cases, of course, interest rates may be raised in the lending country with the deliberate object of checking the movement of capital and gold abroad. [Whale, 1937, p. 29]

Empirical studies have provided evidence that is consistent with Whale's description. W. E. Beach found that gold movements between Britain and the United States (1881–1913) could more easily be associated with changes in interest rates than with changes in prices (Beach, 1935, p. 180). Beach's work is in general agreement with that of A. G. Ford, who notes the "general similarity in the curves of Bank Rate and net imports of gold from Europe [into Britain]" in that era (Ford, 1962, p. 40). C. A. E. Goodhart, using a multiple-regression approach on monthly data, has recently shown that "the Bank [of England] could, in large part, offset the internal drain of gold reserves (and, possibly, an initial external drain) resulting from an increase in domestic activity, by forcing up interest rates sufficiently to induce short-term capital and gold inflows from abroad" (Goodhart, 1972, p. 208).[2] An oblique but ingenious approach to the gold standard problem is taken by Lindert (1969, p. 51), who substitutes the relationship between exchange rates and discount rates for that between gold flows and discount rates (for the years 1899 to 1913) and finds systematic relationships between various pairs of countries.[3] These findings suggest the presence of a relationship between gold movements and interest rates that merits further study.

How can it be shown that this relationship was a significant part of the gold standard adjustment process? The earlier studies mentioned above point in the right direction but are limited, in one case, by an almost exclusive concern with Britain and, in others, by a reliance on annual data or a concentration on the cyclical behaviour of the interest rate and gold movement series. An approach is needed that captures the discrete timing of gold movements and interest rate changes and filters out common influences on both series. If an underlying regular relationship between these series could be identified and described, one part of the adjustment process could be explained and our understanding of the process as a whole advanced.

Identifying such a relationship poses some formidable problems. The selection of an appropriate interest rate is especially difficult. At first glance, it might appear that official discount rates are the proper choice. What makes these rates unsuitable is that they provide neither a continuous reflection of market forces nor a continuous monitoring of central bank policy. It is well known that official discount rates were not *effective* in the market for long periods. Furthermore, certain central banks (e.g., the Bank of France) made very infrequent changes in official discount rates, preferring the use of "gold devices" instead. What is needed is an interest rate that reflects market forces and, at least to some extent, central bank policy as well.

For an investigation that includes Britain, France and Germany, three market discount rates have been chosen. These rates are the London open market discount rate, the Paris open market discount rate and the Berlin private discount rate. The London and Paris rates are those that were charged for the discount of bank bills; the Berlin rate is that which was charged for the discount of prime bills.[4] Because large volumes of transactions of similar classes of bills were conducted at these rates, the three discount rates chosen played comparable roles in their respective financial centres. These rates are available in the form of daily averages for the period under study. (For a discussion of data sources, see Appendix.)

The remaining data required for an examination of the relationship between gold movements and interest rates are available as well. Monthly gold import and export series for Britain (1888–1908), Germany (1892–1908) and France (1900–1908) were published by the US National Monetary Commission. Respective central bank holdings of precious metals are available from the same source.[5] The accuracy of international gold flow data, like that of other international trade statistics, has frequently been challenged. C. F. Ferraris, A. Soetbeer, de Foville, R. Giffen, H. D. White and O. Morgenstern have all questioned the trustworthiness of these data, although such doubts did not prevent White, W. E. Beach and others from using them. In *The Validity of International Gold Movement Statistics*, Morgenstern reports the results of several tests of the validity of these data and concludes that it would be best not to use them (Morgenstern, 1955, pp. 7–8).

There are good reasons for rejecting this Draconian judgment. The empirical work of Goodhart has recently shown that from 1900 to 1913 the UK–US monthly gold flows are "almost identical" in UK and US sources and that the bias that remains "is relatively unimportant taking each month separately ...." (Goodhart, 1972, pp. 83–84). Morgenstern's own tests show that the German gold flow data are reasonably good. Where a perfect correspondence of British and German accounts requires that all ratios equal one, Morgenstern reports 1·12 and 0·81 for 1900 and 1·25 and 0·93 for 1907 (Morgenstern, 1955, p. 12). Certainly, discrepancies of this order of magnitude do not render data worthless. Furthermore, Morgenstern's argument is based almost entirely on discrepancies in data organized by destination or source. To the extent that gold shipments were made to profit from arbitrage opportunities, those shipping gold were very likely more reluctant to divulge the destination of shipments than to divulge their size, which would in any case have been harder to disguise. The data that we use are aggregate gold export and import series so that discrepancies relating to destination or source need not have influenced them.[6] Although other data (e.g., monthly or quarterly money supply series) would also be desirable, we believe that the data series at hand are adequate for an examination of the relationships between interest rates and international gold flows (i.e. external dynamics) and between interest rates and gold flows to and from central banks (i.e. internal dynamics) for the countries mentioned above.

I. The Model Tested

Whale's discussion of adjustment under the prewar gold standard suggests two specific, testable hypotheses relating interest rates to gold movements. The first hypothesis is needed to explore the external dynamics of adjustment and deals with the timing of interest rate changes and external gold *flows*. We test to determine whether the following sequence of events can be shown to have occurred: (1) gold flows out of (into) the country; (2) the interest rate increases (decreases); (3) gold flows out of the country are decreased (increased). Note that a positive test of this hypothesis cannot be used to determine whether interest rate changes result from market forces or deliberate central bank policy. To attempt to make such a distinction, the pattern of interest rate changes between countries can be examined.

A second hypothesis is needed to explore the internal dynamics of adjustment. The presence or absence of a relationship between gold stocks of central banks and changes in interest rates is the question posed by this hypothesis. While on the external side central banks may have been reacting to changes in international gold flows, on the internal side central banks may have been attempting to maintain a given level of gold reserves. Since a given level of central bank gold holdings is not necessarily associated with any one level of interest rates, our analysis must determine whether there is a relationship (possibly dynamic) between changes in the interest rate and gold stocks of central banks. Based on our expectations concerning the conduct of central bank policy, the second hypothesis postulates a negative relationship between the stock of gold held by a central bank and changes in the interest rate. Of course, these relationships may follow with a lag that will be determined by the data, and may differ across countries.

II. Alternative Methods of Testing for Causality

In the previous section we have suggested that one way that the gold standard system might have adjusted is that central banks may have responded to a gold outflow (or a reserve loss) by raising the central bank discount rate (and also the market discount rate). By following this policy the central bank hoped to attract gold back into the country. The resulting gold flow, which may have occurred with some lag after the discount rate increase, would in turn have had an impact on interest markets. Upon first reflection, calculating a regression that predicts net gold outflows as a function of present and past values of the private discount rate seems to be an appropriate procedure for analysing dynamics of this chain of events. Inspection of the t values of regression coefficients might provide a test of the viability of our hypothesis. While such a procedure could be tried, it has serious drawbacks. Since various lagged values of time series are usually highly correlated, estimation of ordinary least squares (OLS) regressions containing present and lagged values of the same variable is usually plagued by multicollinearity. This drawback makes regression an unsatisfactory choice.

Sims (1972) suggested an alternative procedure whereby a test for causality in the Granger (1969) sense could be made by estimating an OLS regression using data filtered with the *same* filter and regressing future, present and past values of X on Y. According to Sims, significance on the future value of X would suggest "feedback" of Y on X and would imply that X was not exogenous, while significance on lagged X alone would suggest that X causes Y. Unfortunately, as Pierce and Haugh (1977) have shown, there is a substantial possibility that the Sims (1972) procedure indicates causality when none exists.[7]

In order to overcome some of the disadvantages of the Sims (1972) procedure, Pierce and Haugh (1977) and Pierce (1977) have suggested that causality should be investigated via a two filter Box–Jenkins procedure whereby both series, X and Y, are filtered by their respective filters prior to the calculation of cross-correlations. While the Sims (1972) procedure was found to have an *upward* bias (i.e. to indicate causality when no causal relationship is present), the Pierce–Haugh two-filter procedure was shown by Sims (1977) to have a *downward* bias (i.e. to fail to indicate causality when a causal relationship is present). The latter bias arises because the two-filter procedure requires estimation of the cross-correlations *conditional* on estimation of the two filters. In the next section a detailed explanation of these biases is provided and a third method of analysis involving a one-filter procedure with specialized diagnostic tests is presented. Our one-filter procedure has neither the upward bias of the Sims procedure nor the downward bias of the Pierce–Haugh procedure.

III. Arguments for the One-Filter Method of Causality Testing

When a transfer function (distributed lag) is estimated between Y_t and X_t of the form

$$(1) \qquad (1 - \delta_1 B - \ldots - \delta_r B^r)\, Y_t = (\omega_0 - \omega_1 B - \ldots - \omega_s B^s)\, X_{t-b} + a_T$$

where B is the lag operator defined such that $B^i Y_t = Y_{t-i}$, the most difficult task is to identify the form of the model.[8] If we write the model in shorthand form as

$$(2) \qquad Y_t = \frac{\omega(B)}{\delta(B)} X_{t-b} + e_t$$

where e_t is the white noise error term defined as $\{\theta_a(B)/\lambda_a(B)\}\, a_T$, then the form of $\omega(B)/\delta(B)$ can be identified two ways. One method involves using *two* filters to prewhiten Y_t and X_t (Box and Haugh, 1977) while the other technique only involves using *one* filter for both series (Box and Jenkins, 1976). We argue below that the technique of using one filter both substantially simplifies the direct economic interpretation of the cross-correlations of the two prewhitened series and does not suffer from the bias (Sims, 1977) associated with the two-filter procedure. Since our objective is to report the cross-correlations, we use the one-filter identification procedure later in the paper.

We will discuss the two-filter procedure first. Since cross-correlations of autocorrelated series may produce spurious results, it is necessary to filter both Y_t

and X_t before the cross-correlations are calculated. If U_{xt} and U_{yt} are the resulting white noise series, then

$$(3) \qquad U_{xt} = \frac{\lambda_x(B)}{\theta_x(B)} X_{t-b}$$

and

$$(4) \qquad U_{yt} = \frac{\lambda_y(B)}{\theta_y(B)} Y_t.$$

If U_{xt} and U_{yt} are cross-correlated, then it is possible to identify the relationship

$$(5) \qquad U_{yt} = \frac{\omega'(B)}{\delta'(B)} U_{xt} + e'_T$$

from which the basic relationship now can be written in terms of the two prewhitening filters as [9]

$$(6) \qquad Y_t = \frac{\theta_y(B)}{\lambda_y(B)} \frac{\lambda_x(B)}{\theta_x(B)} \frac{\omega'(B)}{\delta'(B)} X_{T-b} + e_t.$$

The downward bias of the cross-correlations calculated from the two-filter procedure arises because the relationship $\omega'(B)/\delta'(B)$ is estimated conditional on the two filters being estimated in a prior stage.[10] If, on the other hand, the one-filter method is used, no such bias arises since the two filters are the same ($\theta_y(B) = \theta_x(B)$ and $\lambda_x(B) = \lambda_y(B)$) and can be crossed out.

By using the one-filter procedure, a more traditional method of transfer function model identification, one runs the risk that spurious results can occur if one of the series is not reduced to white noise by the filter of the other series. The one-filter method of analysis can be used if a diagnostic procedure is devised to allow testing for spurious results. The resulting analysis would be preferable to both the upwardly biased Sims (1972) procedure and the downwardly biased Pierce–Haugh (1977) procedure. The diagnostic checking scheme, which we develop more fully below, involves autocorrelating the cross-correlations and comparing this autocorrelation function with the autocorrelation function of the not completely prewhitened series.

IV. Diagnostic Checks on a One-Filter Cross-Correlation Function

Box and Jenkins (1976, p. 377) have studied the problem of spurious cross-correlations arising when either or both of the series are not white noise.[11] Their analysis can be summarized by four prepositions given two series, X_t and Y_t, where both series have been filtered by the same prewhitening filter (the X filter):

(a) If series X_t and Y_t *are* related and both X_t and Y_t are white noise, the cross-correlations of X_t on Y_t and the cross-correlations of Y_t on X_t will indicate the true relationship between the two series.

(b) If X_t and Y_t *are not* related and if one series (say X_t) is white noise and the other series (say Y_t) is *not* white noise, then "in this case the cross-correlations have the same autocorrelation function as the process generating Y_t. Thus, even though X_t and Y_t are *not* cross-correlated, the cross-correlation function can be expected to vary about zero with standard deviation $(n - k)^{1/2}$ in a systematic pattern typical of the autocorrelation function $p_{yy}(j)$."[12]

(c) "If two processes are both white noise and *are not* cross-correlated, then the covariance between the cross-correlations will be zero".

(d) If two series *are* cross-correlated and neither series is white noise, then it is impossible to distinguish between true cross-correlations and spurious results arising from autocorrelations left in the two series.

Proposition (d) states that, if neither series is white noise, there is no way to distinguish spurious from non-spurious cross-correlations Proposition (b), which forms the basis of our proposed diagnostic test, states that, assuming that X_t is a white noise series, if there is no relationship between X_t and Y_t, then the autocorrelations of the cross-correlations will be similar to the autocorrelations of the not completely prewhitened series, Y_t. What follows from proposition (b) is that it is possible to use the one-filter procedure to obtain unbiased estimates of the cross-correlation function between the two series if and only if a test is made to reject spurious cross-correlations via the comparison of autocorrelation functions discussed above.[13] In our view such a procedure makes possible a reliable test of Granger causality.[14]

V. Filter Identification

In Table 1 we have filtered the three interest rate series used in our study by first differencing, seasonal first differencing, and both first differencing and seasonal first differencing. We have tested the autocorrelations of the transformed series by use of the Q statistic,[15] which is distributed as a chi-square statistic. Results reported in Table 1 indicate that, with the exception of one differencing

Table 1

Box–Pierce Q Statistics for Interest Series Filtered Only by Differencing*

Series	$(1-B)$	$(1-B^{12})$	$(1-B)(1-B^{12})$
London open market	$Q(12) = 45\cdot4$**	$Q(12) = 338\cdot0$**	$Q(12) = 123\cdot0$**
Discount rate	$Q(24) = 78\cdot2$**	$Q(24) = 501\cdot0$**	$Q(24) = 143\cdot0$**
1899(1)–1908(12)	$Q(36) = 105\cdot0$**	$Q(36) = 590\cdot0$**	$Q(36) = 156\cdot0$**
Private discount rate	$Q(12) = 145\cdot0$**	$Q(12) = 523\cdot0$**	$Q(12) = 38\cdot5$**
Reichbank	$Q(24) = 262\cdot0$**	$Q(24) = 670\cdot0$**	$Q(24) = 58\cdot0$**
1892(1)–1908(12)	$Q(36) = 389\cdot0$**	$Q(36) = 732\cdot0$**	$Q(36) = 70\cdot4$**
Paris open market	$Q(12) = 38\cdot1$**	$Q(12) = 228\cdot0$**	$Q(12) = 17\cdot8$
Discount rate	$Q(24) = 69\cdot8$**	$Q(24) = 320\cdot0$**	$Q(24) = 32\cdot6$
1900(1)–1908(12)	$Q(36) = 120\cdot0$**	$Q(36) = 423\cdot0$**	$Q(36) = 49\cdot0$

* For all data sources and definitions, see text. All Q statistics marked with ** are significant at the 1 per cent level. For a discussion of the definition and interpretation of the Q statistic, see Nelson (1973). $(1 - B)$ = first differencing, $(1 - B^{12})$ = seasonal first differencing, and $(1-B)(1-B^{12})$ = first differencing and seasonal first differencing.

A significant Q statistic indicates that the output of the differencing filter *does not* transform the series to white noise.

TABLE 2

PREWHITENING FILTERS*

London open market discount rate 1888(1)–1908(12)

$$(1-B)(1-\underset{(2\cdot32)}{0\cdot15029}B^{12})z_t=(1-\underset{(5\cdot44)}{0\cdot32617}B^2-\underset{(1\cdot59)}{0\cdot097749}B^7+\underset{(-2\cdot98)}{0\cdot19209}B^{24}+\underset{(-2\cdot25)}{0\cdot1457}B^{36}+\underset{(-2\cdot50)}{0\cdot16102}B^{37})u_t \qquad RSE=0\cdot5647$$

Autocorrelations of residuals

lag													SE
1–12	0·05	0·01	−0·09	−0·11	−0·02	−0·07	−0·06	−0·05	0·12	0·06	0·07	−0·01	0·065
13–24	0·04	0·02	−0·01	−0·04	−0·09	−0·01	−0·04	−0·04	−0·00	−0·02	0·01	0·02	0·070
25–36	0·04	−0·06	0·04	−0·09	−0·10	−0·01	−0·11	0·01	0·07	0·09	0·01	0·01	0·070
37–48	0·02	0·00	0·00	−0·01	−0·02	0·01	0·03	−0·07	0·05	−0·08	0·02	0·02	0·070

$Q(24)=17\cdot57$

Private discount rate Reichsbank 1892(1)–1908(12)

$$(1-B)(1-B^{12})z_t=(1-\underset{(15\cdot50)}{0\cdot79618}B^{12})u_t \qquad RSE=0\cdot34103$$

Autocorrelations of residuals

lag													SE
1–12	0·13	0·02	0·01	0·04	−0·14	−0·04	−0·10	0·01	−0·03	0·11	−0·06	0·05	0·076
13–24	−0·08	−0·01	−0·09	0·09	−0·02	−0·05	−0·08	0·08	−0·07	−0·02	−0·13	−0·12	0·078
25–36	0·02	0·11	−0·04	0·05	0·06	0·02	−0·05	0·03	−0·08	−0·04	−0·04	0·06	0·082

$Q(24)=25\cdot51$

Paris open market discount rate 1900(1)–1908(12)

$$(1-B)(1-B^{12})(1+\underset{(-5\cdot09)}{0\cdot58559}B^{12})z_t=(1-\underset{(4\cdot65)}{0\cdot59507}B^{24})u_t \qquad RSE=0\cdot27612$$

Autocorrelations of residuals

lag													SE
1–12	−0·00	−0·16	0·14	0·04	0·04	0·03	−0·11	0·07	0·06	−0·05	−0·03	−0·10	0·114
13–24	−0·13	0·02	0·04	−0·15	0·03	0·00	0·04	−0·01	0·10	−0·03	−0·12	−0·03	0·124
25–36	−0·08	0·02	0·04	−0·07	−0·00	0·05	0·01	−0·08	−0·05	−0·02	−0·04	0·12	0·137

$Q(24)=12\cdot62$

* For all data sources and definitions see text. For a discussion of Box–Jenkins prewhitening models see text. *t* statistics are listed under the coefficients.

Note that for the London open market discount rate there appears to be an insignificant 7th-order moving average parameter. However, if this term is dropped from the equation, a significant autocorrelation appears seven periods back (coefficient −0·15). If the model is simplified by dropping the insignificant parameter, all other parameters are within 0·02 of their old values.

filter applied to French interest data (seasonal first differencing and first differencing), all other filters were shown (at the 1 per cent level) *not* to transform the series to white noise for the first 12 months, first 24 months, and first 36 months. What these tests show is that results obtained using data that are "prewhitened" with only a differencing filter would be difficult if not impossible to evaluate, because the absence of white noise in *both* the *X* series (the interest rate) and the *Y* series rules out checks based on proposition (b) of the previous section. The test results reported in Table 1 indicate that we need to estimate and diagnostically to check a true prewhitening filter for the *X* series rather than to use only a differencing filter prior to analysis of the relationship between series *X* and series *Y*.

Such filters have been estimated and the results are given in Table 2.[16] Detailed discussion of ARIMA model identification and estimation is beyond the scope of this paper and may be found in standard works. In Table 2 we merely list both the final filters that we have selected and the autocorrelation of the noise term so that the appropriateness of the filter models can be judged. The Q statistics for the differenced series given in Table 1 can be compared with the Q statistics of the filtered series given in Table 2.

VI. Selection of Interest Rate Filters

The filter selected for the London open market discount rate includes first differencing, estimation of a seasonal autoregressive parameter. All parameters were highly significant except for the 7th-order moving average parameter, which was left in the prewhitening filter to remove a spike in the autocorrelations of the residuals at lag seven. Since the $Q(24)$ statistic (17·57) is well below a chi-square statistic of (24–6) degrees of freedom (28·87 at the 95 per cent level), we can accept the hypothesis that the filter selected is correct and the residuals are white noise. Similar results have been obtained for the Reichsbank private discount rate, except that in this case we estimated only a 12th-order moving average parameter after the series was regular and seasonally differenced. Since the $Q(24)$ statistic is well below the chi-square statistic for the 95 per cent confidence interval with 23 degrees of freedom (35·172), we can again accept the hypothesis that white noise has been obtained. White noise was also obtained for the Paris open market discount rate by the use of regular differencing, seasonal differencing, a 12th-order autoregressive parameter and a 24th-order moving average parameter. After selecting the above three mentioned filters, the next step is to use the same filter to prewhiten both series prior to the calculation of the desired cross-correlations. It is to this task that we turn in the next section.

VII. The Results

Our empirical results include evidence on the following questions for the United Kingdom, Germany, and France.

(a) Did central banks respond to net reserve changes by changing the market discount rate?
(b) Did central banks respond to net gold losses by changes in the market discount rate?
(c) Did changes in the market discount rate have any effect on gold reserve levels held in central banks? If so, what are the dynamics?

To attempt to answer these questions, we have collected data on gold reserves, net gold losses, and the market discount rate for France in the period 1900(1) to 1908(12), for Germany in the period 1892(1) to 1908(12) and for the United Kingdom in the period 1888(1) to 1908(12). (Complete data sources and details on the construction of the series are contained in the Appendix.) For all countries we have calculated cross-correlations between the change in the market discount rate and the gold reserve in the central bank, to study the internal dynamics of the gold standard, and between the change in the market discount rate and the net gold loss from the country, to study external dynamics of the gold standard. In all cases we have prewhitened both series using the same filter that we estimated for the appropriate discount rate series, and have performed the extensive diagnostic tests on the cross-correlations described above. We turn first to France.

TABLE 3

THE WORKINGS OF THE GOLD STANDARD IN FRANCE 1900(2)–1908(12)*

Internal Dynamics

Series 1 Changes in Paris open market discount rate
Series 2 Gold reserve Bank of France

Cross-correlations prewhitened data

Series 2 on lags of Series 1		Series 1 on lags of Series 2	
lag 0	0·014	lag 0	0·014
1	−0·008	1	−0·181
2	0·111	2	−0·129
3	0·139	3	−0·046
4	−0·273	4	0·120
5	−0·008	5	0·107

$SE = 0{\cdot}1098$

Diagnostic Checking

Autocorrelations of prewhitened Series 2

lag													SE
1–12	0·06	−0·01	−0·06	−0·10	−0·05	0·01	0·02	0·03	0·06	0·00	−0·01	−0·02	0·11
13–24	−0·04	0·01	0·07	0·02	−0·01	−0·07	−0·08	−0·11	−0·05	0·01	0·01	0·51	0·12
25–36	0·02	−0·02	−0·08	−0·15	−0·11	0·03	0·04	0·01	−0·00	−0·05	−0·02	−0·02	0·14

$Q(24) = 26{\cdot}670$

Autocorrelations of cross-correlations of Series 2 on lags of Series 1

lag													SE
1–12	−0·01	−0·01	0·25	−0·06	−0·03	0·00	0·06	0·02	0·17	−0·01	−0·09	0·08	0·14
13–24	−0·27	0·01	0·13	−0·20	−0·02	−0·03	−0·09	−0·16	0·10	−0·09	−0·20	0·20	0·16
25–27	−0·16	−0·11	−0·08										0·18

$Q(12) = 61{\cdot}388$

Autocorrelations of cross-correlations of Series 1 on lags of Series 2

lag													SE
1–12	0·09	−0·14	0·15	−0·20	−0·22	0·12	−0·04	0·03	0·11	−0·02	0·04	−0·12	0·15
13–24	−0·35	0·10	−0·02	−0·33	0·09	0·14	−0·09	0·14	0·12	−0·17	−0·04	0·14	0·17
25–27	−0·05	−0·06	−0·04										0·19

$Q(12) = 10{\cdot}074$

External Dynamics

Series 1 Changes in Paris open market discount rate
Series 2 Net gold loss France

Cross-correlations prewhitened data

Series 2 on lags of Series 1		Series 1 on lags of Series 2	
lag 0	0·037	lag 0	0·037
1	−0·203	1	0·033
2	−0·123	2	−0·061
3	0·192	3	−0·010
4	0·027	4	0·095
5	−0·059	5	0·024

$SE = 0{\cdot}1098$

Diagnostic Checking

Autocorrelations of prewhitened Series 2

lag													SE
1–12	0·20	0·07	−0·09	−0·03	−0·17	0·05	0·19	0·15	0·07	0·02	−0·22	−0·44	0·12
13–24	−0·17	0·10	0·04	0·06	0·10	−0·05	−0·24	−0·22	−0·18	−0·07	0·13	0·20	0·16
25–36	0·05	−0·10	−0·19	−0·23	−0·15	0·05	0·15	0·15	0·14	0·01	−0·10	−0·08	0·18

$Q(24) = 54{\cdot}061$

TABLE 3—*cont.*

Autocorrelations of cross-correlations of Series 2 on lags of Series 1

lag													*SE*
1–12	0·10	−0·14	0·10	0·15	−0·12	0·06	0·15	0·16	0·10	0·10	−0·17	−0·35	0·15
13–24	0·02	0·08	0·01	−0·11	0·09	0·00	−0·21	−0·32	−0·11	−0·14	0·08	0·01	0·18
25–27	−0·16	−0·04	−0·02										0·19

$Q(12) = 16{\cdot}681$

Autocorrelations of cross-correlations of Series 1 on lags of Series 2

lag													*SE*
1–12	0·25	0·03	0·12	0·10	0·04	0·10	−0·07	−0·06	0·04	0·02	−0·18	−0·40	0·14
13–24	−0·21	−0·02	−0·12	−0·08	−0·01	−0·16	−0·03	0·01	−0·08	0·02	0·05	0·01	0·18
25–27	−0·01	0·00	−0·01										0·18

$Q(12) = 16{\cdot}808$

* Although only 5 cross-correlations have been reported, 54 have been used in the calculation of the autocorrelations of the cross-correlations. For data sources, see text. Filter used was estimated using series 1. For the autocorrelations of this series and the filter used, see Table 1.

The cross-correlations of the internal dynamics of the gold standard for France (shown in Table 3) indicate weak evidence of a negative relationship between French gold reserves and changes in the market discount rate (see correlations −0·181). The finding is consistent with a hypothesis that suggests that market forces (the loss of gold reserves) moved the discount rate, and it is also consistent with a hypothesis that the central bank influenced the French market discount rate in response to the reserve loss. Inspection of the autocorrelations of the filtered gold reserve series in comparison to the autocorrelations of both sets of cross-correlations indicates that they are not similar. The conclusion is that both sets of cross-correlations that we have reported are not spurious. Cross-correlations between gold reserves and lags of changes in the market discount rate are consistent with the surprising result that, four months after a positive change in French market discount rate, the Bank of France lost gold (see correlation −0·273). Clearly, other forces, not previously specified, are needed to explain this result. In seeking such an explanation we have cross-correlated the prewhitened French market discount rate with both the German private discount rate and the British market discount rate in the years 1900–1908. Our results suggest that changes in the German private discount rate led by one month (correlation coefficient 0·198) changes in the French market discount rate, and that changes in the French market discount rate led changes in the British market discount rate (correlation coefficient of 0·243) by three months.[17] This latter finding could explain the puzzling result reported above. The evidence we have cited suggests that changes in the market discount rate originated in Germany, moved to France with a one-month lag and then on to Britain with a three-month lag. This pattern might explain why gold was drawn out of the Bank of France four months after the French market discount rate rose, since we later show that, one month after the British discount rate rose, gold flowed in.

Evidence for the external dynamics of the gold standard in France suggests that the market discount rate *does not* move after an increase in net gold exports, but there is evidence that, one month after a positive change in the market discount rate (correlation −0·203), there is a net gold flow into France. The explanation for the French loss of gold three months after a positive change in the market discount rate (see correlation 0·192) is consistent with the findings on the

TABLE 4

THE WORKINGS OF THE GOLD STANDARD IN GERMANY 1892(1)–1908(12)*

Internal dynamics

Series 1 Changes in private discount rate Reichsbank
Series 2 Metal reserve Reichsbank (*Metallvorrat*)

Cross-correlations prewhitened data

Series 2 on lags of Series 1		Series 1 on lags of Series 2	
lag 0	−0·110	lag 0	−0·110
1	0·147	1	0·013
2	−0·019	2	−0·158
3	0·091	3	0·073
4	−0·045	4	−0·073
5	−0·075	5	0·069

$SE = 0{\cdot}0747$

Diagnostic Checking

Autocorrelations of prewhitened Series 2

lag													*SE*
1–12	−0·04	−0·06	−0·04	−0·03	−0·03	0·01	−0·05	−0·04	−0·06	−0·09	−0·06	0·76	0·08
13–24	−0·06	−0·05	−0·04	−0·03	−0·03	−0·00	−0·05	−0·03	−0·04	−0·08	−0·05	0·59	0·11
25–36	−0·06	−0·05	−0·04	−0·02	−0·01	0·01	−0·02	0·00	−0·01	−0·02	−0·03	0·47	0·13

$Q(24) = 176{\cdot}58$

Autocorrelations of cross-correlations of Series 2 on lags of Series 1

lag													*SE*
1–12	−0·51	0·46	−0·47	0·34	−0·32	0·30	−0·44	0·37	−0·45	0·40	−0·41	0·64	0·21
13–24	−0·43	0·30	−0·38	0·22	−0·22	0·21	−0·29	0·29	−0·29	0·29	−0·26	0·43	0·35
25–27	−0·28	0·17	−0·26										0·38

$Q(12) = 124{\cdot}79$

Autocorrelations of cross-correlations of Series 1 on lags of Series 2

lag													*SE*
1–12	−0·25	0·12	−0·49	0·26	−0·26	0·04	−0·28	0·24	−0·19	0·08	−0·25	0·63	0·16
13–24	−0·21	0·06	−0·23	0·16	−0·04	0·15	−0·16	0·13	−0·05	0·06	−0·27	0·26	0·24
25–27	−0·16	0·10	−0·20										0·26

$Q(12) = 50{\cdot}920$

External Dynamics

Series 1 Changes in private discount rate Reichsbank
Series 2 Net gold loss Germany

Cross-correlations prewhitened data

Series 2 on lags of Series 1		Series 1 on lags of Series 2	
lag 0	0·075	lag 0	0·075
1	0·065	1	0·214
2	0·004	2	0·070
3	0·019	3	−0·070
4	−0·072	4	−0·013
5	0·083	5	0·065

$SE = 0{\cdot}0747$

Diagnostic Checking

Autocorrelations of prewhitened Series 2

lag													*SE*
1–12	−0·07	−0·07	0·02	0·13	0·03	−0·17	−0·01	0·00	−0·01	−0·05	0·01	0·14	0·08
13–24	−0·10	−0·03	0·06	0·03	−0·02	−0·18	0·03	−0·02	−0·04	−0·11	−0·09	0·23	0·08
25–36	0·05	−0·07	0·05	0·01	0·04	−0·10	0·04	−0·03	−0·01	−0·15	0·02	0·14	0·09

$Q(24) = 36{\cdot}039$

TABLE 4—*cont.*

Autocorrelations of cross-correlations of Series 2 on lags of Series 1

lag													*SE*
1–12	0·20	−0·05	0·12	0·09	−0·07	−0·32	−0·14	−0·11	−0·12	−0·01	−0·05	0·10	0·15
13–24	0·02	0·05	0·13	0·03	0·13	−0·10	−0·03	−0·08	−0·09	−0·05	−0·14	0·08	0·17
25–27	0·11	−0·02	0·08										0·17

$Q(12) = 12{\cdot}770$

Autocorrelations of cross-correlations of Series 1 on lags of Series 2

lag													*SE*
1–12	0·19	0·04	0·08	0·07	−0·13	−0·23	−0·16	−0·17	−0·03	0·11	−0·05	0·13	0·15
13–24	−0·03	0·05	0·04	0·01	−0·12	−0·19	−0·17	−0·07	−0·21	−0·08	−0·11	0·08	0·17
25–27	0·05	0·14	0·14										0·18

$Q(12) = 11{\cdot}430$

* Although only 5 cross-correlations have been reported, 54 have been used in the calculation of the autocorrelations of the cross-correlations. For data sources, see text. Filter used was estimated using Series 1. For the autocorrelations of this series and the filter used, see Table 1.

internal side, except that adjustment appears to be faster by one month on the external side. Diagnostic tests for the French external dynamics cross-correlations suggest that our findings for France are not spurious.

Evidence for internal dynamics of the gold standard in Germany are presented in Table 4. Here the evidence clearly shows that two months after the Reichsbank loses reserves there is a positive change in the private discount rate (see correlation −0·158). This increase, in turn, results in gold reserves rising (see correlation 0·147) after one month. Thus, while in a manner similar to that in France, we see the Reichsbank (or the market) responding to a gold loss with a private discount rate increase, in contrast to France, the increase in the private discount rate attracted gold reserves (with one-month lag). Except for some seasonality (12th-order) in the filtered gold reserve series, which appears to be reflected in the cross-correlations, the diagnostic tests give us confidence in our cross-correlations.[18] It is important to note that, although we have found that upward changes in the discount rate increased the metal reserve of the Reichsbank, there is *no* evidence that the net gold outflow changed. This evidence is consistent with our result, which suggests that one month after the Reichsbank raised its private discount rate the Bank of France increased the Paris market discount rate. While there is evidence that the increase in the French market discount rate caused gold to flow into France, the Germans did not gain gold as a result of their private discount rate movement. The Reichsbank appears to have attempted to defend Germany from gold outflows (see correlation of 0·214 between a one-period lag of the German gold loss on the German private discount rate) only to have had its efforts counteracted by actions of foreign central banks. It is important to note that diagnostic tests on our German external dynamics findings are very good, indicating that our correlation of 0·214 alluded to above is clearly *not* spurious.

Our analysis of the workings of the gold standard in the United Kingdom are given in Table 5. Cross-correlations for internal dynamics in the present period show that, when the Bank of England lost (gained) reserves, changes in the market discount rate were positive (negative) (see correlation −0·221). This pattern indicates that either the market or the Bank of England is responding very

TABLE 5

THE WORKINGS OF THE GOLD STANDARD IN THE UNITED KINGDOM 1888(1)–1908(12)*

Internal Dynamics

Series 1 Changes in the London open market discount rate
Series 2 Gold Reserve Bank of England (Issue Department)

Cross-correlations prewhitened data

lag	Series 2 on lags of Series 1	Series 1 on lags of Series 2
0	−0·221	−0·221
1	0·060	−0·113
2	0·099	0·016
3	0·036	−0·049
4	0·061	0·032
5	0·013	0·021

$SE = 0{\cdot}0648$

Diagnostic Checking

Autocorrelations of prewhitened Series 2

lag													*SE*
1–12	−0·39	0·25	−0·09	0·07	−0·07	0·12	0·03	−0·01	−0·04	0·01	0·01	−0·04	0·08
13–24	0·13	0·02	−0·13	0·17	−0·19	0·11	−0·04	0·05	−0·15	0·16	−0·01	−0·12	0·08
25–36	0·08	−0·14	0·03	−0·15	0·11	−0·08	−0·05	0·02	−0·10	0·01	0·00	0·06	0·09

$Q(24) = 102{\cdot}93$

Autocorrelations of cross-correlations of Series 2 on lags of Series 1

lag													*SE*
1–12	−0·53	0·31	−0·30	0·04	0·01	−0·09	0·23	−0·28	0·33	−0·47	0·39	−0·36	0·19
13–24	0·39	−0·10	−0·06	0·08	−0·28	0·28	−0·17	0·26	−0·30	0·20	−0·14	0·03	0·27
25–27	0·02	−0·03	0·17										0·29

$Q(12) = 66{\cdot}830$

Autocorrelations of cross-correlations of Series 1 on lags of Series 2

lag													*SE*
1–12	−0·24	0·32	−0·15	−0·02	−0·09	−0·17	−0·03	−0·19	0·04	−0·01	0·09	0·10	0·15
13–24	0·15	−0·05	−0·04	−0·05	−0·14	−0·01	−0·03	−0·13	0·03	0·07	0·17	−0·04	0·17
25–27	0·19	−0·14	0·02										0·18

$Q(12) = 14{\cdot}859$

External Dynamics

Series 1 Changes in the London open market discount rate
Series 2 Net gold loss United Kingdom

Cross-correlations prewhitened data

lag	Series 2 on lags of Series 1	Series 1 on lags of Series 2
0	0·185	0·185
1	−0·217	0·204
2	−0·127	0·062
3	−0·033	−0·039
4	−0·038	−0·133
5	−0·029	−0·066

$SE = 0{\cdot}0648$

Diagnostic Checking

Autocorrelations of prewhitened Series 2

lag													*SE*
1–12	0·41	0·25	0·22	0·10	0·14	0·14	0·09	0·06	0·17	0·02	0·06	0·11	0·07
13–24	0·11	0·14	0·05	0·05	−0·01	−0·07	−0·09	−0·07	−0·05	−0·03	−0·04	−0·18	0·09
25–36	−0·11	−0·17	−0·19	−0·20	−0·19	−0·22	−0·23	−0·16	−0·19	−0·09	−0·10	−0·18	0·10

$Q(24) = 112{\cdot}02$

TABLE 5—*cont.*

Autocorrelations of cross-correlations of Series 2 on lags of Series 1

lag													SE
1–12	0·31	0·08	−0·08	−0·20	−0·12	−0·16	−0·09	−0·06	−0·05	−0·11	0·12	0·12	0·15
13–24	0·21	0·16	0·04	−0·03	−0·19	−0·16	−0·21	−0·09	−0·06	0·04	0·10	0·09	0·17
25–27	0·02	0·09	0·09										0·19

$Q(12) = 13{\cdot}157$

Autocorrelations of cross-correlations of Series 1 on lags of Series 2

lag													SE
1–12	0·54	0·28	0·00	−0·24	−0·31	−0·31	−0·22	−0·18	0·10	0·10	0·22	0·22	0·18
13–24	0·12	0·07	−0·07	−0·10	−0·22	−0·18	−0·31	−0·18	−0·01	0·11	0·24	0·22	0·23
25–27	0·16	−0·06	−0·10										0·25

$Q(12) = 45{\cdot}182$

* Although only 5 cross-correlations have been reported, 54 have been used in the calculation of the autocorrelations of the cross-correlations. For data sources, see text. Filter used was estimated using Series 1. For the autocorrelations of this prewhitened series and the filter used, see Table 1.

quickly to reserve losses (gains). This rapid adjustment contrasts with slower adjustment that we observed in France and Germany.

Turning to the external dynamics in the United Kingdom, we see that, one month after an increase in net gold outflow, the market discount rate increases (see correlation of 0·204). While this result is consistent with theory, there is some evidence in the diagnostic tests that the result might be due to incomplete prewhitening of the net gold loss series. Evidence that, one month after the British market discount rate increases, the United Kingdom gains gold (see correlation −0·227) is consistent with the theory and does stand up when subjected to diagnostic testing. The correlation of 0·185 in the immediate period, in contrast to our findings for France or Germany, suggests that either the Bank of England or market forces drive up (down) the market discount rate when there is a net gold outflow (inflow).

VIII. CONCLUSION

Our first hypothesis, that international gold flows triggered interest rate changes, which in turn influenced those gold flows, can be confirmed only for Britain. Our results show that in France interest rates influenced gold flows but not the reverse. In Germany the opposite result was obtained; international gold flows triggered interest rate changes but those changes do not appear to have influenced gold flows. Our second hypothesis, that there was a regular relationship between central bank gold stocks and changes in the level of interest rates, can be confirmed for each of the countries studied. Evidence for this relationship is strongest for Britain but is also present in the results of our tests for Germany and France.

How might Whale have viewed these results? Our findings appear to be broadly consistent with Whale's understanding of this aspect of prewar gold standard adjustment. The kind of "exhaustive testing" he urged appears to show that the pattern of gold movements and interest rate changes was very much as his section V described it. Because the gold reserve of the Bank of France was more than ample, gold could flow out of France without leading to an increase in interest rates. In Britain and Germany, where gold reserves were less abundant, gold outflows did lead to increases in interest rates for which central banks were most likely responsible. Whale, we think, would be pleased.

ACKNOWLEDGMENTS

The authors wish to acknowledge the generous support of the Columbia University Council for Research in the Social Sciences. Computer time for this study was provided by the Computer Center of the University of Illinois. The authors are grateful to Professor Arcadius Kahan and several anonymous referees for helpful suggestions and to Ms. Diane Peterson for data preparation. Any errors or omissions are the responsibility of the authors.

APPENDIX: DATA SOURCES

Gold import and export data were obtained from US National Monetary Commission, *Statistics for Great Britain, Germany, and France, 1867–1909* (Washington: US Government Printing Office, 1910); British gold imports and exports, p. 65; German gold imports and exports, pp. 247–250; French gold imports and exports, p. 346. Net gold outflow is defined as gold exports minus gold imports.

Coin and bullion in the Issue Department of the Bank of England were obtained from the same source, pp. 90–100; gold reserve of the Bank of France, pp. 305–313. *Metallvorrat* (metal reserve) of the Reichsbank obtained from *Die Reichsbank 1876 bis 1910* (Berlin: Reichsdruckerei, 1912), pp. 28–31.

Discount rate data were obtained from Statistische Abteilung der Reichsbank, *Vergleichende Notenbank-Statistik* (Berlin: Reichsdruckerei, 1925), Table 127, pp. 212–231. Average monthly rates have been used. Note that footnote 1, p. 212, gives the sources of these data as follows: "on the basis of daily exchange quotations from official rate reports or from Wolff's Depeschen: for Berlin since 1876, for London and Paris since 1896, for Vienna and Petersburg since 1897, otherwise from the dispatches of the Deutscher Reichsanzeiger or from the English *Economist* . . .." As a source for London and Paris discount rates, the Reichsbank is preferable to the US National Monetary Commission because the former gives daily averages whereas the latter gives only four or five observations per month.

NOTES

[1] Under the so-called "rules of the game", central banks were supposed to accelerate adjustments to balance of payments disequilibria. See Triffin (1964, pp. 2 ff).

[2] Note that Goodhart's conclusions are based on equations reported in footnotes 25 and 27 on p. 204 and footnote 30 on p. 205.

[3] Whatever the merits of this approach in studying countries whose monetary authorities depended heavily on foreign "key currency" holdings as reserves, another is needed where gold was relied upon. As Lindert himself notes, Britain and France relied mainly on gold reserves (p. 35), so that the functioning of the gold standard system in these countries is best explored by examining gold flows rather than exchange rates. After 1896 the Reichsbank did pursue an active *Devisenpolitik* (foreign exchange policy) based on substantial foreign exchange holdings (chiefly sterling). Even in the German case, study of gold flows is preferable to that of (bilateral) exchange rates for two reasons. Although they could be converted into gold, foreign exchange holdings did not count as cover for the Reichsbank note issue, so that foreign exchange could be used to satisfy some gold standard requirements (e.g. maintaining fixed currency parities) but not others (e.g. maintaining the metallic reserve required by law). Furthermore, as M. Seeger (1968, p. 36) points out, the foreign exchange policy of a central bank had to be kept within narrow limits if it was not to be counterproductive. When the foreign exchange market was at or near equilibrium, Reichsbank purchases of sterling could easily have pushed sterling up to the gold export point and caused gold to flow out of Germany (Seeger, 1968, p. 36). Under these circumstances, sterling reserves could have been adjunct to but not a substitute for Reichsbank gold reserves.

[4] In choosing these discount rates, we implicitly ignore the problem of distinguishing between central bank and market influences on interest rates. These rates reflect both influences. For a discussion of these rates, see Morgenstern (1955, pp. 120–123 and pp. 433–441).

[5] The Reichsbank reports provide monthly totals only for its *Metallvorrat* (metal reserve) which was composed chiefly of gold and silver but also included small amounts of other metals. This series was used in the tests reported below.

[6] Our results concerning the external dynamics of gold standard adjustment in France must be read with caution. It is, of course, possible that inaccurate data may provide the basis for results that are consistent with theory, our understanding of institutional behaviour, and evidence from other countries. None the less, we believe that the Box–Jenkins technique we have used (explained below) so reduces the chance of obtaining spurious results that our findings concerning France merit serious consideration.

[7] Pierce and Haugh (1977, p. 279) note that Sims (1972) selected his filter so that the residuals of this equation was uncorrelated. They note, "One thus suspects that in the application of this procedure, in those cases where the prechosen filter leaves substantial serial correlation in the filtered series, it is possible that causality may be believed to have been found where it does not exist. That this may have occurred in the case of money and income, the principle focus of the study by Sims [1972], is suggested by the findings of Feige and Pearce [1974]." Further evidence of this nature is contained in Feige and Pearce (1976). An additional problem with the Sims procedure is that the results it yields are very difficult to interpret in an economic context because of the presence of future terms in the regression equation.

[8] This section is rather brief; it builds on the analysis of the identification of a transfer function model treated in Box and Jenkins (1976) for single-filtering techniques and Box and Haugh (1977, pp. 121–130) and Granger and Newbold (1977) for two-filter techniques. Readers who accept that the same prewhitening filter can be used can skip to the next section.

[9] We have ignored the noise model specification in terms of the prewhitening filters in order to simplify the presentation. In general,

$$e_t = \frac{\theta_y(B)}{\lambda_y(B)} e'_t.$$

[10] Defining omitted variables as having the form $c(B)\,X$, Sims (1977) notes: "Anyone versed in the theory of least-squares regression will recognize this as involving a bias in favour of the null hypothesis, except in the special case when the omitted variables are uncorrelated with the included variables."

[11] Nelson defines white noise as a "sequence of identically and independently distributed random disturbances with mean zero and variance σ_μ^2." See Nelson (1973, p. 31).

[12] (Quoted from Box and Jenkins, 1976, p. 377, with notational changes.) If $p_{yy}(j)$ is the autocorrelation of series y_t, j periods apart and $r_{xy}(k)$ is the cross-correlation of series x_t and y_t, k periods apart, Box and Jenkins have proved that

$$p\{r_{xy}(k), r_{xy}(k+j)\} \simeq p_{yy}(j)$$

where the first term refers to the autocorrelation of the cross-correlations j periods apart. This work builds on the pioneering paper by Bartlett (1935, pp. 536–543).

[13] The testing procedure is as follows. First, a filter is identified which reduces the X series to white noise. Next, this same filter is applied to the Y series and the autocorrelations of this "filtered" series are calculated. Two sets of cross-correlations are calculated between the prewhitened X series and the Y series (which has been filtered with the X series prewhitening filter). At this point there are two vectors of cross-correlations. One vector, which is reported on the left-hand side of our tables, shows the cross-correlations between Y_t and X_{t-k} where k ranges from 0 to 54 (in the tables we have reported 0 to 6). The other vector, reported on the right-hand side of the tables, shows the cross-correlations between X_t and Y_{t-k} where k ranges from 0 to 54. The diagnostic testing procedure involves calculation of separate autocorrelations of these two cross-correlation coefficient vectors, which are then compared individually to the autocorrelations of the possibly not completely prewhitened Y series. If for example, we find that the autocorrelations of the not completely prewhitened series (Y) is similar to the autocorrelations of the cross-correlations of X_t and Y_{t-k}, then we can dismiss any "significant" cross-correlations found, arguing that they are spurious and resulted from the process discussed in proposition (b) above. In order for us to argue that X_{t-k} for some k is significantly correlated with Y_t, two conditions must be met. First, we must find that the autocorrelation of the cross-correlations of Y_t and X_{t-k} (for k going from 0 to 54) are *not* similar to the autocorrelations of the possibly not completely prewhitened series (Y); and, second, we must detect a significant cross-correlation between Y_t and X_{t-k} for some specific k.

[14] An alternative to cross-correlation analysis is the estimation of a transfer function. There are several grounds for not pursuing this approach. A serious concern is that the estimation of a transfer function model in the presence of possible feedback is very complicated at best and remains the subject of much as yet unresolved controversy (see Granger and Newbold, 1977). What makes estimation of a transfer function an even less attractive choice is that the economic interpretation of the coefficients of the transfer function is much more difficult than that of the cross-correlations we

have reported. Because our objective is investigation of the causal dynamics of the gold standard system, cross-correlation analysis is a viable method of analysis. Cross-correlation analysis, in contrast to regression analysis, cannot directly tell us the relative magnitude of the effect under study. However, its usefulness in this situation is that it is sufficient to establish the significance or lack of significance of the relationship under study.

[15] To test whether a series is prewhitened we have reported the Q statistic which is distributed as a chi-square statistic with $n - k$ degrees of freedom. Further discussion of the construction and use of the Q statistic can be found in Nelson (1973). In addition, we have reported the average *SE* for each row of autocorrelations, where the *SE* for the kth lag correlation r_k

$$SE_{r_k} = \sqrt{\left\{(1/N)\left(1 + 2\sum_{j=1}^{k-1} r_j^2\right)\right\}}.$$

[16] For a very clear discussion of the filter selection process, readers may consult Pindyck and Rubinfield (1976, Chapters 13–17). Table 2 gives a Q statistic which is distributed as a chi-statistic and gives an indication of the significance of the first 24 autocorrelation coefficients. If $Q(i)$ is significant, then for the first i autocorrelation coefficients we cannot accept the hypothesis that the residuals are white noise and must select additional filter parameters in the model. The degrees of freedom of the Q statistic equals i minus the number of parameters estimated in the filter. Further discussion of the construction and use of the Q statistic can be found in Nelson (1973, p. 115).

[17] Our results show that three months after the Bank of France market discount rate rose two events occurred simultaneously; the English market discount rate rose, and France lost gold. Since any gold flow from France to Britain would *lower* the market rate in Britain, the rise in the Bank of England private discount rate makes it likely that forces other than those of the market were responsible for this increase in the London open market discount rate. Nothing more than likelihood can be claimed because the economies of the three countries studied did not comprise a closed system and events elsewhere have not been taken into account.

[18] Since we do not report any more than 5 cross-correlations, the 12th-order autocorrelation will not affect our results. In calculating the autocorrelations of the cross-correlations we have used 54 cross-correlations.

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