SPOT AND FUTURES PRICES AND THE LAW OF ONE PRICE

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ABSTRACT

The law of one price (LOP) is tested for narrowly defined commodities traded in futures markets in different countries during the period 1973-1980. Although the LOP holds as an average tendency for most of the commodities, there are instances of large riskless arbitrage returns (before transactions costs). One cannot conclude from this that international commodity markets are inefficient or that arbitrage fails to take place since large gross returns to arbitrage may be explained by tariffs or large costs of arbitrage that we do not observe directly. Deviations from the LOP tend to be commodity specific rather than due to a common external factor and they tend to be smaller the longer the maturity of the futures contract.

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SPOT AND FUTURES PRICES AND THE LAW OF ONE PRICE

I. Introduction:

In this paper we examine how well the Law of One Price (LOP) holds for commodities traded internationally. This question is important for two reasons. The first is that in most modern theories of exchange rates it is necessary to have price arbitrage for at least some goods so that the level of exchange rates is determinate. But recent empirical research on the behavior of various price indices casts doubt on the empirical validity of the LOP across countries, even for the most disaggregated indices.

In order for the LOP to be used in building a theory of exchange rates it is necessary that it hold for some individual commodities, but it is not necessary that it hold for price indices. Thus, analyzing the price behavior of well-defined, internationally traded commodities can provide some guidance as to whether it is valid to use the LOP assumption in exchange rate models. If it is not possible to identify any commodities for which the LOP works satisfactorily, then models incorporating the LOP will not provide an adequate description of exchange rates. The converse is not true, however, because the existence of some commodities which satisfy the LOP is not sufficient to insure that models incorporating the LOP give a useful description of exchange rates.

The second reason for studying individual commodities is to gain information on the efficiency and the degree of integration of international commodity markets.

II. A Brief Overview:

The Law of One Price (LOP) predicts that, for a standard commodity, prices in two markets expressed in a common currency will not differ but for transport costs:

$$(1) \qquad P = P^{*}\Pi\tilde{U}$$

where P and P* are domestic and foreign prices for the commodity, Π is the exchange rate expressed in units of domestic currency per unit of foreign currency and $\tilde{U}$ is a random variable constrained by the export-import points. The domestic import point, M, is the upper bound on the domestic price relative to the foreign price. Assuming symmetry, the domestic export point is $\frac{1}{M}$, the lower bound on the domestic price relative to the foreign price. Thus

$$(2) \qquad \frac{1}{M} < \tilde{U}_j < M .$$

Taking the natural logarithm of (1) gives

$$(3) \qquad p = p^{*} + \pi + \tilde{u} , \qquad -m < \tilde{u} < m$$

where the lower case letters indicate logs. The value of m is not generally specified but is assumed to be close to zero in most statements of the theory.

In its most general form the theory of Purchasing Power Parity (PPP) maintains that the exchange rate is proportional to the ratio of the price levels in two countries.[1] The simplest version of the monetary theory of exchange rate determination is based on a world economy is which deviations from PPP are not expected for any commodity. In more sophisticated models, where a distinction between traded and non-traded goods is made (see Dornbusch 1976), deviations from LOP are expected for non-traded goods, although not in response to all disturbances.[2] Unanticipated monetary or fiscal changes, demand changes, or disturbances that originate in the exchange market itself will lead to relative price changes so that PPP will not hold when measured with broad price indices. Indeed deviations will be systematic and relatively long lived, inducing balance of payments adjustments.

All stable asset models of exchange rate determination require that traded goods prices obey the LOP. A necessary condition for PPP as a theory of exchange rate determination is that international arbitrage and the LOP operate for at least some goods; for without the potential movement of some goods, no economic ties exist between two countries. The study of the LOP is therefore an important ingredient in assessing the usefulness of PPP as an exchange rate theory. Recent studies (e.g. Isard, 1977) aimed at testing PPP have narrowed their investigation to disaggregated price indices most likely to follow LOP. We narrow our investigation even further to the level of individual commodity prices.

The study of the LOP is also important for its own sake as a test of the efficiency and degree of integration of international commodity markets. An efficient market is one in which profitable arbitrage, after transaction costs, is not possible. Empirical tests may be able to reject the LOP as a foundation for the PPP theory of exchange rates because of the size of transaction costs while, at the same time, unable to reject the market efficiency hypothesis.

Empirical studies at the level of general price indices (e.g., Gailliot, 1970 and Genberg, 1978) generally support PPP as a long run theory but frequently find significant short run deviations. Studies at the level of disaggregated price indices reach a wide range of conclusions from outright rejection to qualified acceptance of the LOP. Isard (1977), using annual data on four and five digit SITC price indices for Canadian, German and Japanese industrial goods concludes that

> "In reality the law of one price is flagrantly and systematically violated by empirical data. This paper presents evidence that exchange rate changes substantially alter the relative dollar-equivalent prices of the most narrowly defined

> domestic and foreign manufactured goods ... Moreover, these relative price effects seem to persist for at least several years and cannot be shrugged off as transitory."

Kravis and Lipsey (1978) "... think it unlikely that a high degree of national and international commodity arbitrage ... is typical of the real world." Richardson (1978) concludes that "when commodity arbitrage takes place, it is never perfect." Crouhy-Veyrac, Crouhy and Melitz {CVM} (1980) compare commodity prices between the U.S. and France at the eight digit level (individual commodities), and conclude, on a more optimistic note that,

> "All in all, the law of one price emerges as a much less precarious, although a more qualified statement, than has been heretofore implied."

Roll (1979) adopts an approach for testing PPP that is based on the theory of intertemporally efficient markets. Using monthly data on aggregate price indices for twenty-three countries and twenty years, he concludes that

> "the current exchange rate is an excellent predictor of the subsequent month's exchange adjusted inflation rate difference between two countries, and no other past information used here adds to the predictive power."

While deviations from PPP exist, such deviations are intertemporally unpredictable. As a result, Roll rejects theories of the exchange rate that depend on a slow adjustment of prices to PPP, arguing instead that expected relative prices are constant. Since there is a "rapid adjustment of less than one month's deviation," Roll concludes that "goods must be easily shipped or else producers are skillful in diverting productive factors to their highest return locations."[3]

In this paper we examine the LOP as it applies to commodities traded on futures markets in different countries. The data we use are free of many of the problems faced by other investigators. One of the difficulties with past studies that use price indices is that product mix and product quality are not constant in price indices. In fact, competition in product differentiation could cause the nature of products contained in a particular index to diverge systematically across countries. As a result, LOP can hold for individual commodities while failing for indices. Commodities traded on futures markets are well defined, and these definitions remain uniform over time. Price observations in different countries can be matched to the day. Here the LOP can be investigated in its purest form. In a recent monograph, Jain (1980) also examines the LOP as it applies to commodity futures prices. However, he examines a smaller set of commodities over an earlier time period. In addition, as will be noted below, there are difficulties in his regression specifications and in the procedure he uses to account for transportation costs.[4]

Our findings are consistent with those of Kravis and Lipsey (1978), Richardson (1978) and others. Commodity prices adjusted for the exchange rate are equalized in the long run. However, the dependence is frequently loose, the adjustment to the LOP is frequently slow, and apparent riskless gross profit opportunities are easy to identify. These results indicate that transport costs, information costs and other trade barriers are significant. We find that deviations from LOP are not highly correlated across commodities but arise largely from shocks in the individual commodity markets. Systematic deviations from LOP are reduced when we implicitly take account of arbitrage costs, and the variability of the deviations from the LOP is found to diminish with maturity of the futures contract.

The remainder of the paper is organized as follows. After a description of the data in the next section (and in Appendix A), some difficulties encountered in previous tests of the LOP are discussed and initial regression results for 12 commodities are presented. In section V data are classified by time to maturity, and deviations from the LOP are shown to decline with increases in maturity. In section VI, a dummy variable procedure is used to account for arbitrage bands, and this significantly improves the regression properties. The autocorrelation and cross correlation structure of deviations from the LOP are analyzed in section VII. In section VIII the international commodity arbitrage process is examined more closely and riskless arbitrage returns are calculated from the futures price data. Finally the study is summarized and conclusions are presented in Section IX.

III. Description of the Data:

Spot, futures and/or forward price data were collected for standardized commodities traded in more than one country and one currency. A forward contract has a constant time to maturity--i.e., three months--and a changing maturity date, whereas a futures contract has a fixed maturity date but its time to maturity is constantly changing. Futures contract profit and losses are also settled daily while payments on a forward contract are made at maturity.[5] Observations are taken on Wednesday of each week in the post-1972 period of floating exchange rates.[6] The data utilized in the study are summarized in Appendix A.

There are a variety of difficulties with this data set. Frequently, we were forced to use bid prices, not transactions prices; and transactions prices will not be exactly comparable in time because commodity exchanges do not open and close simultaneously. Futures contracts in different countries do not always refer to exactly identical commodities, and spot prices may refer to a range of commodity qualities. Finally, while the price relationship depends on transport and storage costs, such data were not available to us. Despite these difficulties, we can argue that these are the most precise data presently available, not only in terms of comparability of commodities but also in the comparability of the observation time. The most detailed data previously examined in CVM (1980) rely on monthly data for which neither the timing of the price collection nor the exact commodity definitions are as clear.

IV. Initial Tests of the Law of One Price:

A. Problems in Testing the Law of One Price

While early tests of LOP were based on the ratio, $P/P^*\Pi$, more recent empirical tests of the LOP, in the case of individual commodities or narrow commodities groups, have generally relied upon a regression implied by (3):

$$\tilde{p} = a_0 + a_1 p^* + a_2 \pi + \tilde{u} \tag{4}$$

where the null hypothesis is $a_0 = 0.00$ and $a_1 = a_2 = 1.00$.[7] In this approach, one of the commodity prices is taken as exogenous.[8] For any individual commodity or group of commodities this is incorrect. While exchange rates can be taken as exogenous to a particular commodity price, prices of a commodity in two countries are simultaneously determined regardless of the relative size of the countries. This is because information is shared in these markets and because agents operate in more than one market at a time. To assume otherwise would result in improper estimation of (4). To remedy this problem we estimate regressions of the form

$$\tilde{p} - \tilde{p}^* = a_0 + a_1 \tilde{\pi} + \tilde{u} \tag{5}$$

which explicitly account for the joint determination of the two prices. Even this is not totally satisfactory since p and p* are nominal prices and are therefore affected by some of the general macroeconomic conditions that determine the exchange rate. However, our data are taken at weekly intervals over which general macroeconomic changes are expected to be small by comparison to those events affecting the prices of a commodity. Thus any simultaneous equation bias in (5) is expected to be small.

Past studies of the LOP have not usually attempted to treat explicitly costs of commodity arbitrage, choosing instead to infer those costs from the results and the regression tests. We follow that procedure in the tests we report based on (5). Difficulties arise in estimating a_1 in (5) when arbitrage costs are large and most observations fall within the export-import points where commodity arbitrage is not profitable. Consider the case in which one is initially on the LOP line at A in Figure 1 and the exchange rate moves by v. Since the marginal cost of arbitrage, m, is not met, there is no change in $p - p^*$. Only if the point A is located along one boundary or the other will estimates of $a_1 = 1.00$ be implied. In effect regression estimates of a_1 will suffer an attenuation bias similar to that of error in variables.[9] Jain (1980) attempts to account for arbitrage costs by first-differencing (4), implicitly assuming that arbitrage costs are constant over time. This is clearly inappropriate since, as is evident in (3), arbitrage costs may be $-m$ or $+m$. Jain's procedure is appropriate only if all observations lie along the upper or lower band, in which case the arbitrage cost would be reflected in the constant term and would be eliminated by first differencing. Later in this paper we deal with the transport cost problem by using a dummy variable procedure to classify data within the bands, when estimating (5).

B. The LOP Ratio

The natural logarithm of the LOP ratio, $p-p^*-\pi$, calculated over all data available for a particular commodity is examined first.[10] This variable, $p-p^*-\pi$, can be interpreted as the proportional deviation from the LOP, which is equivalent to the deviation from (5) in which a_0 and a_1 are restricted to

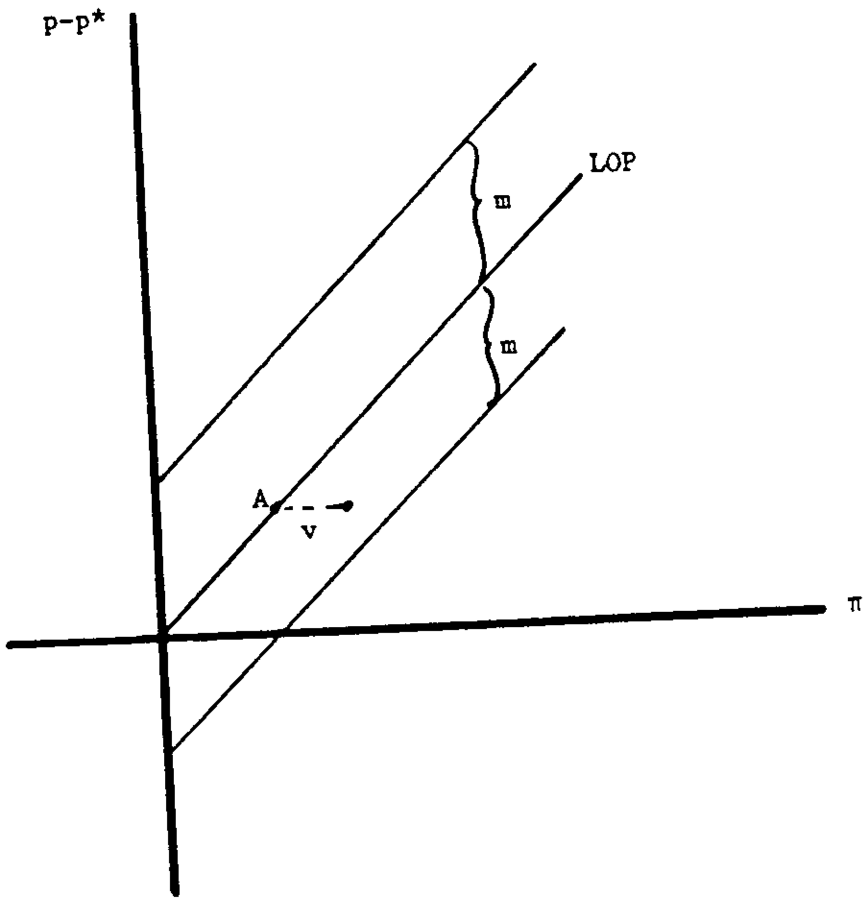

Figure 1

0 and 1, respectively. The mean and standard deviation of the natural logarithms of the LOP ratio, the ratio of prices (p-p*), and the exchange rate (π), are given in Table 1.

In the case of the metals--silver, copper, tin, lead, zinc--there is little systematic deviation from the LOP. The average deviation for spot silver is less than .05%. The largest average deviation is 4.6% in the case of spot tin. In the case of silver and 3-month copper, the standard deviation of (p-p*-π) is small--on the order of 1/5th the standard deviation of (p-p*)--indicating relatively few instances of large deviations from the LOP. However, the standard deviation is large in the case of the spot metals (except tin) implying the existence of substantial deviations from the LOP.

For the internationally traded commodities--coffee, cocoa, sugar--there also appears to be little systematic deviation from LOP except in the case of coffee. The nearly 20 percent average deviation there implies that average U.S. coffee prices were high in comparison to U.K. coffee prices.

In the case of the grains--wheat and soybean meal--there are substantial negative deviations from LOP, which imply high U.K. prices relative to U.S. prices. The U.K. wheat contract refers to European Economic Community (EEC) wheat, deliverable only in the U.K. and subject to the floor and ceiling prices set under EEC rules. U.K. soybean meal is deliverable in Rotterdam; but prices, although affected by EEC conditions, are not as restricted as wheat prices. Thus the deviations, especially for wheat, are not unexpected in light of EEC agricultural policy.

In the case of spot rubber prices in the U.K. and Malaysia, and spot wool prices in U.K. and Australia, deviations from LOP are on the order of eight percent, which must be judged to be small, particularly since spot prices are being used.

Table 1

Means and (Standard Deviations)

Commodity	Variable			Observations
	(p-p*)	π	(p-p*-π)	
Silver spot	.7516 (.1387)	.7511 (.1348)	.00046 (.0200)	427
Silver 3 months[a]	.7183 (.1332)	.7233 (.1325)	-.00500 (.0146)	80
Silver 6 months[a]	.6792 (.1263)	.6788 (.1225)	.00047 (.0134)	64
Copper spot	.7599 (.1263)	.7561 (.1343)	.0038 (.1959)	440
Copper 3 months[a]	.7617 (.1395)	.7487 (.1419)	.0116 (.0258)	47
Tin spot	.8023 (.1384)	.7562 (.1343)	.0461 (.0421)	438
Lead spot (.1856)	.7764 (.1343)	.7561 (.1776)	.0202 (.1776)	440
Zinc spot	.7443 (.2994)	.7561 (.1343)	-.0118 (.3439)	440
Coffee (pooled)	.9177 (.3904)	.7187 (.1284)	.1991 (.0941)	528
Cocoa (pooled)	.6743 (.1461)	.7129 (.1386)	-.0386 (.0795)	925
Sugar (pooled)	.6322 (.1572)	.7209 (.1422)	-.0888 (.0385)	307
Soybean mean (pooled)	.4909 (.0935)	.6409 (.0991)	-.1500 (.0404)	219
Wheat (pooled)	.3894 (.2411)	.6199 (.0943)	-.2305 (.2023)	372
Rubber	-1.4820 (.1381)	-1.5691 (.1057)	.0871 (.0825)	280
Greasy wool	.4162 (.1054)	.4956 (.0899)	-.0794 (.0463)	290

While we do not want to conclude too much from these summary statistics, it is probably safe to say that the LOP is on average reasonably well satisfied, except in the cases of coffee, soybean meal and wheat. However, there are substantial deviations from the LOP, that imply a lack of association of prices and exchange rates. We turn now to a detailed examination of this association.

C. Regression Tests of the Law of One Price

We estimate regressions of the form (5) for each commodity. When spot or forward prices are available we estimate a single regression covering the whole time period. In the case of futures prices, we pool all contracts in a given commodity and estimate a single regression. The pooled regression results and the regressions for spot and forward prices are in Table 2.

Two facts bearing on the statistical significance of the results should be kept in mind. First, as is evident from the Durbin Watson (DW) statistic, there is substantial serial dependence in the residuals so that the standard errors of the coefficients are biased downwards. Second, the pooling of futures contracts in coffee, cocoa and wheat results in some overlap in time. This overlap also biases downward the standard errors because of the contemporaneous correlation across different contracts in the same commodity.

The results are mixed. Using standard statistical tests on a_1 (conservative in view of the downward bias in the standard error of a_1), one cannot reject the LOP for 3- and 6-month silver, 3-month copper, spot tin, cocoa, spot rubber, or spot wool. On the other hand, a_1 appears to differ significantly from one in the case of spot silver, spot copper, spot lead, spot zinc, coffee, sugar, soybean meal and wheat. However, in view of the substantial serial correlation of the error term, some of these values of a_1 may, in fact, not be significantly different from one.[11] Nevertheless, even

Table 2
Regression Tests of the Law of One Price

$$p - p^* = a_0 + a_1\pi$$

Commodity	a_0 (s.e.)	a_1 (s.e.)	r^2 and s.e. of reg.	D.W.	Observations and Time Period
Silver spot	-.0108 (.0054)	1.0144 (.0071)	.9797 .0196	1.423	427 1/5/72-5/28/80
Silver 3 months	-.0047 (.0092)	.9995 (.0125)	.9880 .0147	1.2670	80 12/27/72-5/28/80
Silver 6 months	-.0168 (.0093)	1.0254 (.0135)	.9894 .0131	1.390	64 3/27/74-4/30/80
Copper spot	.4455 (.0491)	.4158 (.0639)	.0882 .1797	.0589	440 1/5/72-7/30/80
Copper 3 months	.0381 (.0203)	.9664 (.0266)	.9669 .0256	.5617	47 2/6/72-6/27/79
Tin spot	.0601 (.0115)	.9815 (.0150)	.9078 (.0421)	.5781	438 1/5/72-7/30/80
Lead spot	.3369 (.0460)	.5812 (.0599)	.1767 (.1686)	.0953	440 1/5/72-7/30/80
Zinc spot	.9658 (.0811)	-.2929 (.1056)	.0173 (.2971)	.0269	440 1/5/72-7/30/80
Coffee (pooled)	-.0713 (.0200)	1.3762 (.0274)	.8274 .0808	.1847	528 9/72-9/79
Cocoa (pooled)	-.0503 (.0067)	1.0164 (.0092)	.9299 (.0387)	.5387	925 5/17/72-6/27/79
Sugar (pooled)	-.1368 (.0109)	1.0803 (.0147)	.9687 .0299	.6579	308 3/73-3/79
Soybean meal (pooled)	-.0613 (.0169)	.8616 (.0260)	.8338 .0381	.4108	219 1975-1979
Wheat (pooled)	-.5195 (.0682)	1.4663 (.1088)	.3292 .1977	.0346	372 3/76-9/79
Rubber spot	.1628 (.0735)	1.0482 (.0467)	.6442 .0825	.1119	280 1/74-12/79
Greasy wool spot	-.1068 (.0152)	1.0553 (.0302)	.8086 .0461	.4984	290 1/2/74-12/26/79

if the standard error is tripled, a statistically significant systematic deviation from LOP remains in the case of spot copper, spot lead, spot zinc and coffee.

Even when the LOP is satisfied, temporary deviations arise, the importance of which is measured by the residual variance or by $(1-R^2)$. As is evident from the Durbin-Watson statistic, these deviations are serially correlated. We attempt to eliminate serial correlation by first differencing and by applying the Cochrane-Orcutt transformation. (The results of taking first differences are presented in Appendix Table B.) These procedures reduce or eliminate serial correlation while driving the slope coefficient toward zero. The slope coefficients become smaller because, in the short run, prices of commodities do not adjust to small movements in the exchange rate, a point which was illustrated in Figure 1.

We are not confident that applications of these procedures is justified since the source of serial dependence is likely to be a misspecification of LOP when stated as (5). The LOP holds only at the upper or lower arbitrage boundary. Since observations may be drawn from the upper boundary, lower boundary or anywhere in between, pooling has the effect of combining observations which follow different regression models. Infrequent switches from one boundary to the other would have the effect of inducing substantial positive serial dependence. Also, movement along an arbitrage band may involve serial dependence. First differencing and Cochrane-Orcutt procedures do not necessarily eliminate these difficulties; and, in this case, application of these procedures simply appears to magnify behavior within the arbitrage bands as opposed to behavior at the bands.[12] In section VI we use a technique that attempts to deal with the arbitrage bands problem.

V. The Law of One Price in the Short Run and in the Long Run:

It is typically the case that spot and near term futures prices exhibit greater variability than prices of futures contracts maturing in the more distant future. This is because the effect of unanticipated shocks on prices can be more readily mitigated when there is time to adjust supplies. The same reasoning applies to the LOP. The same commodity markets in different countries are subject to different shocks that cause prices to diverge. It is cheaper to arbitrage price differences if there is time. Thus one expects wider deviations from the LOP the less the time to maturity of the futures contract. This proposition can be tested by classifying data by time to maturity.

The data for the five commodities--coffee, cocoa, sugar, soybean meal, wheat--in which futures contracts (as opposed to forward contracts) exist, are divided into "near" data and "far" data. Near data include all price observations with less than six months to maturity. A characteristic of these data series is that, within each series, there is not more than one observation per commodity at any point in time. For certain commodities--sugar and soybean meal--data gaps exist in each series because only one futures contract per year was usable. For others--coffee, cocoa and wheat--the near and far series are continuous.[13] The near and far data series are the basis for most of the remaining empirical tests.

The mean and standard deviation of the deviations from the LOP and regression statistics for equation (5) are presented in Table 3 for the "Near" and "Far" classifications. While the regression coefficients are not related to time to maturity, the standard deviations around the LOP ratio and the residual variances from the regressions decline with maturity in all cases except for wheat. The same trend is clearly evident in the spot and forward

Table 3

Law of One Price

Near Term vs. Far Term

Commodity	$(p-p^*-\pi)$ Mean (St. Dev.)	$p-p^* = a_0 + a_1\pi$ a_0 (s.e.)	a_1 (s.e.)	r^2 s.e.r.	D.W. obs.
<u>COFFEE</u>					
"Near"	.1804 (.0936)	-.0696 (.0302)	1.3448 (.0411)	.8122 .0828	.1185 250
"Far"	.2159 (.0914)	-.0820 (.0250)	1.4179 (.0345)	.8599 .0740	.1737 278
<u>COCOA</u>					
"Near"	-.0406 (.0377)	-.0312 (.0120)	.9871 (.0163)	.9241 .0377	.4157 304
"Far"	-.0382 (.0290)	-.0658 (.0079)	1.0388 (.0108)	.9646 .0285	.7626 338
<u>SUGAR</u>					
"Near"	-.0979 (.0456)	-.1734 (.0216)	1.1045 (.0295)	.9115 .0438	.8807 138
"Far"	-.0809 (.0301)	-.1243 (.0106)	1.0602 (.0143)	.9702 .0287	.6401 170
<u>SOYBEAN MEAL</u>					
"Near"	-.1529 (.0471)	.0080 (.0238)	.7530 (.0361)	.7907 .0399	.5200 117
"Far"	-.1466 (.0309)	-.1557 (.0209)	1.0144 (.0328)	.9051 .0310	.3568 102
<u>WHEAT</u>					
"Near"	-.2518 (.1872)	-.4662 (.1161)	1.3467 (.1869)	.2351 .1915	.0319 171
"Far"	-.2100 (.1571)	-.6088 (.0930)	1.6510 (.1499)	.3923 .2047	.0353 190

price for silver and copper (Table 1 and 2). The F-test is used to determine whether the variances of the residuals from the "Near" and "Far" regressions are significantly different; the null hypothesis, H_{01}, is that they are the same. We also test whether the variances of the deviations from the LOP are greater for the "Near" relative to the "Far" data; the null hypothesis, H_{02}, is that they are the same. At a 5 percent level of significance H_{01} is rejected in 6 of 8 cases (the exceptions are coffee and the 3-month/6-month ratio in silver); and H_{02} is rejected in 6 of 8 cases (the exceptions are wheat and the 3-month/6-month ratio in silver). The evidence supports the alternative hypothesis that the variance of deviation from LOP declines with maturity of the futures or forward contracts. It implies that arbitrage costs are a decreasing function of time to maturity and that the LOP is more nearly satisfied in the long run than in the short run.

VI. Accounting for Arbitrage Bands in Regression Tests of the Law of One Price:

A difficulty with the standard regression tests of equation (5) is that observations at each arbitrage band are pooled along with observations inside the band. In effect, the following regression models are pooled:

(6a) Lower band: $p-p^* = a_0+a_1\pi+u_2$; $a_0 < 0$, $a_1 = 1$,

(6b) Upper band: $p-p^* = b_0+b_1\pi+u_1$; $b_0 > 0$, $b_1 = 1$,

(6c) Middle: $p-p^* = c_0+c_1\pi+u_3$; $c_0 = ?$, $c_1 = ?$.

If arbitrage costs are large, such pooling can bias coefficients, and infrequent shifts from one arbitrage band to the other could induce the positive serial correlation observed earlier.[14]

In the absence of information on transactions costs, the data cannot explicitly be divided into the three categories. Instead we use a dummy variable procedure to classify the data by size of deviation from the mean value of the LOP ($p-p^*-\pi$). Data are classified with respect to the mean rather than the theoretical value of zero because for certain commodities most of the observations fall primarily on one side of the theoretical value.[15] This seems to be the result of quotas and the tax and tariff structures for the commodity. If this classification procedure causes the slope coefficient to move closer to the LOP value of unity, and reduces the serial correlation of the residuals, it would provide support for the LOP with transactions costs. On the other hand, if the classification procedure has no effect, we would conclude that behavior at the bands is no different than in the middle, which would be evidence against the LOP with transactions costs.

Define two dummy variables as follows:

$$D_1 = 1 \text{ if } (p-p^*-\pi) > \mu + ns, \text{ 0 otherwise}$$

$$D_2 = 1 \text{ if } \mu - ns < (p-p^*-\pi) < \mu + ns, \text{ 0 otherwise}$$

where μ and s are respectively the mean and standard deviation of ($p-p^*-\pi$) and n ranges from 0 to $\frac{1}{2}$. We estimate the following regression:[16]

$$(7) \qquad p - p^* = a_0 + b_0 D_1 + c_0 D_2 + a_1 \pi + u$$

While alternative classifications are used, in Table 4 we report the results for $n = \frac{1}{4}$ only; observations within $\pm \frac{1}{4}s$ are classified as the middle band.

Almost without exception, classifying the data via the dummy variable procedure dramatically improves results in the sense described earlier--the slope coefficient is closer to the theoretical value of one, the serial correlation as measured by the Durbin-Watson statistic is reduced, and the standard error of the regression is lowered significantly. For example, in

"Far" soybean meal the Durbin-Watson statistic increases from .3568 (Table 3) to 1.657 while the slope remains very close to its theoretical value. In "Far" coffee the slope declines from 1.4179 to 1.1171 while the Durbin-Watson statistic increases from .1737 to .4470. The standard error of the regression declines by over 40% in these two cases. Similar improvements appear in the other commodities.

Despite the classification procedure, the coefficient of the exchange rate appears to remain significantly different from one in a number of cases. However, these are also cases in which the Durbin-Watson statistic is below unity. Since low D.W. statistics mean that the standard errors of the coefficients are seriously understated the results suggest that a more direct specification of arbitrage costs might ultimately confirm a modified LOP in all the cases we examine.

Relatively little can be concluded from the value of the intercept and the coefficients of the dummy variables since they are determined in part by our classification procedure. The estimated intercept for the lower band is a_0 and that of the upper band is $a_0 + b_0$. Thus the measure of average arbitrage costs implied by our classfication procedure is b_0. In most cases the upper and lower band straddle the theoretical LOP line. However, in the case of "Far" cocoa, sugar, soybean meal and wheat, both bands lie below the LOP line, which implies that U.S. prices are systematically below U.K. prices. In "Far" coffee, both bands lie above the LOP line.

VII. Behavior of Deviations from the Law of One Price:

A. Auto-correlation Structure of Deviations from LOP.

Central to some models of the balance of payments is the proposition that deviations from purchasing power parity are persistent and thereby set in motion adjustment through real transfers of goods and services. Roll (1979)

Table 4

Regression Tests of LOP with Dummy Variables

$$p - p^* = a_0 + b_0 D_1 + c_0 D_2 + a_1 \pi$$

Commodity	a_0 (s.e.)	b_0 (s.e.)	c_0 (s.e.)	a_1 (s.e.)	S.E.R. D.W.
Silver spot	-.0147 (.0041)	.0344 (.0018)	.0185 (.0017)	.9948 (.0053)	.0142 1.512
Silver 3 month	-.0245 (.0061)	.0274 (.0024)	.0150 (.0026)	1.0063 (.0078)	.0091 1.2083
Silver 6 month	-.0124 (.0060)	.0275 (.0026)	.0095 (.0023)	1.0046 (.0086)	.0080 1.6676
Copper spot	-.2038 (.0302)	.4408 (.0121)	.3345 (.0126)	.8494 (.0341)	.0894 .4785
Copper 3 month[a]	-.0132 (.0101)	.0553 (.0041)	.0332 (.0042)	.9958 (.0122)	.0144 1.3361
Tin spot	-.0054 (.0062)	.0798 (.0023)	.0345 (.0030)	1.0201 (.0079)	.0216 1.404
Lead spot	-.1005 (.0304)	.3366 (.0113)	.2058 (.0131)	.8844 (.0360)	.0971 .4660
Zinc spot	-.4190 (.0630)	.7761 (.0248)	.6406 (.0238)	.7493 (.0690)	.1621 .2306
Coffee "Near"	-.0063 (.0169)	.1673 (.0070)	.0880 (.0078)	1.1385 (.0241)	.0454 .5610
Coffee "Far"	.0064 (.0180)	.1608 (.0081)	.0709 (.0072)	1.1171 (.0270)	.0474 .4470
Cocoa "Near"	-.0710 (.0070)	.0731 (.0029)	.0453 (.0033)	.9816 (.0092)	.0213 .8170
Cocoa "Far"	-.0819 (.0045)	.0547 (.0021)	.0296 (.0024)	1.0187 (.0062)	.0162 1.405
Sugar "Near"	-.1416 (.0156)	.0710 (.0060)	.0321 (.0084)	1.0159 (.0221)	.0307 1.252
Sugar "Far"	-.1146 (.0052)	.0598 (.0026)	.0278 (.0028)	1.0081 (.0074)	.0140 1.280

Table 4, Continued

Commodity	a_0 (s.e.)	b_0 (s.e.)	c_0 (s.e.)	a_1 (s.e.)	S.E.R. D.W.
Soybean meal "Near"	-.1368 (.0180)	.0761 (.0053)	.0345 (.0079)	.9154 (.0249)	.0239 .8570
Soybean meal "Far"	-.1698 (.0089)	.0651 (.0028)	.0290 (.0033)	.9919 (.0137)	.0123 1.657
Wheat "Near"	-.5038 (.0452)	.3996 (.0128)	.1392 (.0169)	1.1810 (.0725)	.0738 .4352
Wheat "Far"[a]	-.4437 (.0352)	.4620 (.0119)	.1687 (.0132)	1.0716 (.0566)	.0683 .8516
Rubber spot	-.1366 (.0392)	.1633 (.0056)	.0857 (.0068)	.9765 (.0247)	.0411 .7240
Wool spot	-.1434 (.0091)	.0873 (.0035)	.0443 (.0040)	1.0394 (.0175)	.0262 1.3651

[a]Copper 3 month and wheat "Far" data are classified into $\pm 1/2$ standard deviation around mean because $\pm 1/4$ standard deviation produced only 6 and 8 observations, respectively, in the middle.

concludes that deviations from PPP in aggregate price indices do not persist so as to yield positive expected returns from the transfer of real goods and services and concludes that these slow adjustment models of the balance of payment are not supported by his data. The data on the individual commodities examined in this study do exhibit substantial persistence in deviations from the LOP. Since we are dealing with known futures prices both of the commodity and of the currency, we show that persistent before-transaction-cost riskless returns to the shipment of the commodities exist.

Deviations from the LOP show substantial autocorrelation as indicated by the Durbin-Watson statistic in Table 3. A more detailed picture of the autocorrelation structure for the "Near" series in each commodity, presented in Table 5, confirms that result. While the level of autocorrelation varies across commodities, all autocorrelations are significant at lag 2, and all but silver are significant at lag 5. Except for silver, autocorrelation coefficients decline monotonically with the lag length. The standard error for the autocorrelation of lag 8 is calculated on the assumption that the true order of the autocorrelation structure is k-1.[17]

While high autocorrelations are not consistent with the very rapid adjustment of prices found by Roll, they do not necessarily contradict Roll's conclusion that deviations from PPP are insufficient to induce trade flows, since the observed deviations may not be large enough to overcome transport costs and other barriers to the movement of goods.

B. Cross-Commodity Dependencies

Implicit in some models of exchange rates is the view that deviations from the LOP are induced by monetary and fiscal policy changes that affect all commodities. These models imply the need to incorporate in (5) one or more additional exogenous factors, other than the exchange rate. In order to assess the extent to which deviations from LOP are due to a common factor, we calculate the contemporaneous cross-correlations of the deviations from the LOP. The cross-correlations for the "Near" maturities are reported in Table 6 for commodities traded in the U.S. and the U.K. While four of the six cross-correlations for wheat are statistically significant, only two of the remaining 15 cross-correlations are significant. Furthermore, there is a downward bias in the measured standard error that results from serial correlation of the deviations, and it causes the statistical significance to be overstated. A comparison of Table 6 and Table 5 shows that the largest cross-correlation is generally less than the serial correlation for the commodity.

The evidence in Table 6 suggests that deviations from the LOP are commodity specific, and that common exogenous factors are not needed to explain the ratio or prices of a commodity in two countries. Thus, the evidence suggests that movements in exchange rates do not systematically change the terms of trade across commodities. The evidence also suggests that there is not a common macro-economic adjustment mechanism that involves these commodities, that comes into play when prices deviate from the LOP. While deviations from the LOP appear to persist over time because of arbitrage costs, there is no clear evidence of common behavior of different commodities within the arbitrage bands.

VIII. The Arbitrage Process:

A. Theory

An alternative though related way of studying the LOP is to examine the arbitrage process. Examining the arbitrage process shifts the emphasis from whether the LOP "holds" to whether unexploited price arbitrage opportunites seem to exist. These questions are distinct, because it is possible that

Table 5

Auto-Correlation Structure of Deviations From The LOP
Auto-Correlation Coefficient for $(p-p^*-\pi)$
And Standard Error (in parentheses)[a]

Commodity	Lag in Weeks 1	2	5	8	12
Silver spot	.2885 (.0489)	.2594 (.0529)	.0344 (.0720)	.2626 (.0890)	.1864 (.1268)
Copper spot	.9738 (.0481)	.9551 (.0820)	.8815 (.1377)	.7964 (.1731)	.6882 (.2013)
Coffee "Near"	.9507 (.0682)	.8857 (.1173)	.7754 (.1964)	.6477 (.2370)	.5094 (.2691)
Cocoa "Near"	.8014 (.0627)	.6853 .0989	.2459 (.1348)	.1055 (.1399)	-.0824 (.1385)
Sugar "Near"	.4865 (.0902)	.5375 (.0994)	.4472 (.1494)	.3329 (.1757)	.2821 (.1902)
Soybean mean "Near"	.7953 (.0953)	.7504 (.1469)	.5073 (.2293)	.5227 (.2978)	.2999 (.4091)
Wheat "Near"	.9828 (.0767)	.9617 (.1349)	.8939 (.2315)	.8290 (.2916)	.7814 (.3511)
Wool spot	.7453 (.0605)	.6435 (.0887)	.4790 (.1248)	.3020 (.1418)	.0502 (.1477)
Rubber spot	.9434 (.0617)	.9124 (.1044)	.7981 (.1725)	.7219 (.2109)	.6846 (.2486)

[a]See footnote 16 for definition of standard error.

Table 6

Correlation Matrix for Contemporaneous Deviations from the LOP with Standard Errors in Parentheses

	Silver	Copper	Coffee	Cocoa	Sugar	Soybeans	Wheat
Silver spot							
Copper 3 Months	-.0873 (.1562)						
Coffee "Near"	.1809* (.0639)	.0383 (.1644)					
Cocoa "Near"	.0912 (.0603)	.2224 (.1644)	.1159 (.0658)				
Sugar "Near"	.1629 (.0854)	.1249 (.2236)	.2737* (.0953)	-.1677 (.0949)			
Soybean meal "Near"	.0226 (.0925)	.0530 (.2673)	-.0687 (.1231)	-.0026 (.1098)	-.0535 (.1601)		
Wheat "Near"	.1621* (.0741)	.0698 (.2182)	.4334* (.0848)	.3145* (.0803)	.5894* (.1162)	.0937 (.1098)	

Notes: Asterisk (*) indicates the correlation is statistically signficant at the 5% level.

barriers to trade are large enough to make the LOP fail while no arbitrage possibilities are left unexploited.

The arbitrage process that establishes the LOP is frequently assumed to take place instantaneously at spot prices. But because transport takes time, the purchase of a commodity in one country and its sale in another country cannot be simultaneous. Thus uncertainty about the selling price generally exists and arbitrage is not riskless. Futures markets can eliminate this source of uncertainty by making it possible to fix a selling price in the futures market at the time the arbitrage process is initiated.

In order to consider the alternative arbitrage opportunities, we make our notation more precise. Let

p_0 = natural logarithm of the spot commodity price.

p_1 = natural logarithm of the commodity futures price observed at the same time as the spot price.

In a corresponding manner, π_0 and π_1 refer to the logarithm of the spot and futures exchange rates. As before, an asterisk (*) will identify a foreign price. Note that $\pi = -\pi^*$.

Ruling out instantaneous spot arbitrage, the domestic or foreign arbitrager has three arbitrage strategies. The returns to these strategies are represented by the lengths of the line segments that connect prices of the commodity at different points in space and time in Figure 2. Opportunities facing the domestic arbitrager are expressed in units of domestic currency. Opportunities facing the foreign arbitrager are expressed in units of foreign currency.[18] As the arrows indicate, commodity arbitrage can be in either direction in space but can only be in one direction in time.

Storage. One strategy is storage of the commodity. The continuously compounded gross rate of return to this activity--the basis--is $b = p_1 - p_0$ in the home country, and $b^* = p_1^* - p_0^*$ in the foreign country. Since storage will occur whenever the basis exceeds the marginal cost of storage ($\hat{b}$ or $\hat{b}^*$), the magnitude of the basis is limited as follows:

(8a) Domestic: $b = p_1 - p_0 \leq \hat{b}$

(8b) Foreign: $b^* = p_1^* - p_0^* \leq \hat{b}^*$

There is no lower limit on the basis, which may be negative during periods of spot shortage of the commodity, as it often happens just before a harvest.

<u>Export</u>. A second strategy is export of the commodity for delayed delivery in the other country. In units of domestic currency, the gross rate of return to this activity is $x = p_1^* + \pi - p_0$, a certain return that must cover the costs of transport through space and through time (including tariffs and taxes). The upper limit on x is set by the proportional cost of exporting the commodity--the export points ($\hat{x}$ and $\hat{x}^*$) --which yields the following conditions on the return to exporting:[19]

(9a) Domestic: $x = p_1^* + \pi_1 - p_0 \leq \hat{x}$

(9b) Foreign: $x^* = p_1 - \pi_1 - p_0^* \leq \hat{x}^*$

<u>Import</u>. A third strategy is to import the commodity that yields a gross return of $y = p_1 - p_0^* - \pi_0$ for the domestic arbitrager. The upper limit on y is set by the proportional cost of importing the commodity--the import points ($\hat{y}$ and $\hat{y}^*$)--which are, in equilibrium, determined by the tariff and other costs associated with importing the commodity. Thus

(10a) Domestic: $y = p_1 - p_0^* - \pi_0 \leq \hat{y}$

(10b) Foreign: $y^* = p_1^* - p_0 + \pi_0 \leq \hat{y}^*$

It should be noted that none of the above six returns to arbitrage need be the same. For example, the basis may differ across countries because of differences in interest rates and other storage costs over the time period of the storage (arising from differences in expected inflation, for example). Similarly, the returns over time to importing or exporting differ because of these time-related factors.

The deviation from the LOP at a moment of time is, however, the same whether viewed from the domestic or foreign perspective. The deviation from LOP may be derived from the arbitrage opportunities available to the domestic or foreign arbitrager even in the absence of instantaneous arbitrage, because storage and importing provide alternative sources of future supply and therefore constrain the price of the commodity at any time. The deviation from LOP in the spot market is the same as the return to importing net of the basis. From (10) and (8)

$$y-b = -(y^{*}-b^{*}) = p_0-p_0^{*}-\pi_0 \; . \tag{11}$$

The deviation from LOP in the futures market is the same as the return to exporting net of the basis. From (9) and (8)

$$x-b = -(x^{*}-b^{*}) = p_1^{*}+\pi_1-p_1 \; . \tag{12}$$

Given the import and export points in each country, the LOP implies the following constraints:

<u>Spot Market LOP</u>

$$-(\hat{y}^{*}-b^{*}) < p_0-p_0^{*}-\pi_0 < \hat{y}-b \tag{13}$$

<u>Futures Market LOP</u>

$$-(\hat{x}-b) < p_1-p_1^{*}-\pi_1 < \hat{x}^{*}-b^{*} \tag{14}$$

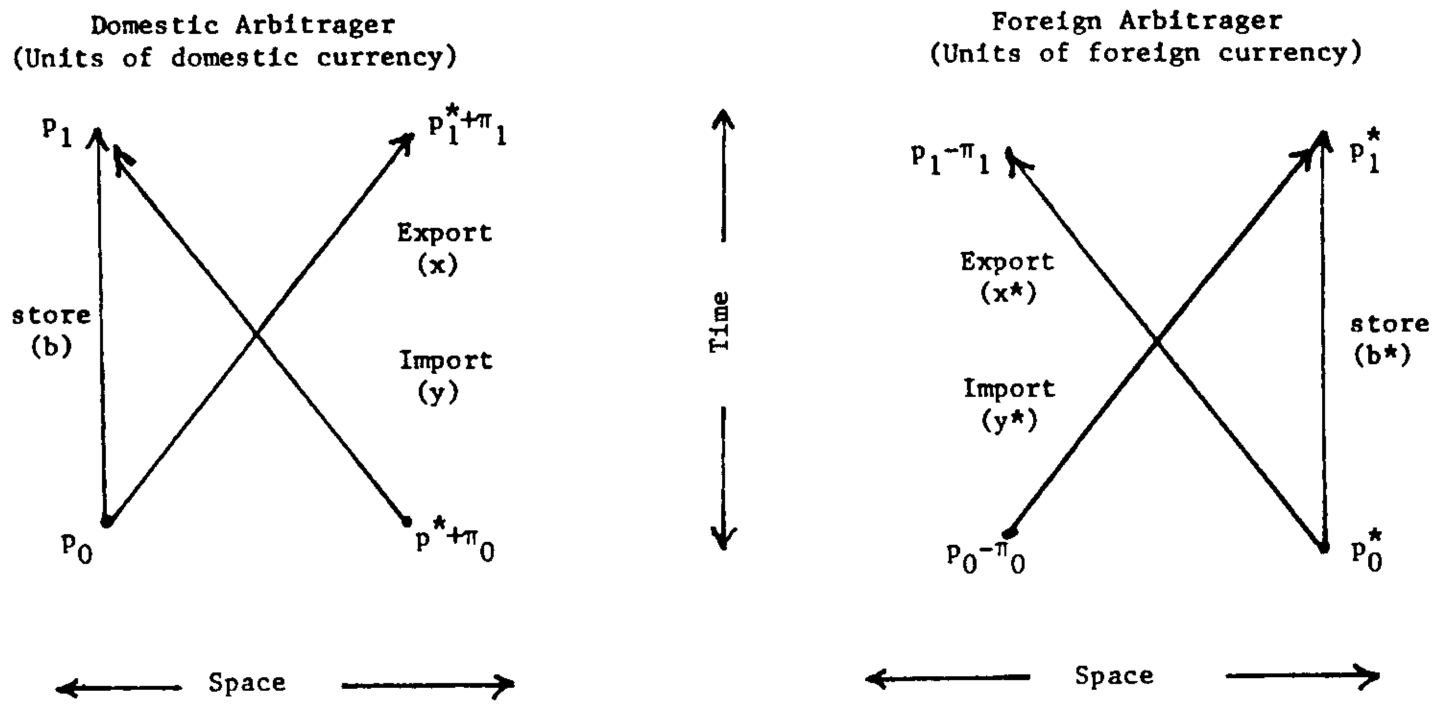

Figure 2. Returns to Arbitrage

For commodities in continuous production, the basis in each country is zero, and the interpretation of (13) or (14) is that given in textbooks: condition (13) then says that the domestic spot price, p_0, cannot exceed the foreign price expresssed in domestic currency, $p_0^* + \pi_0$, by more than the domestic currency cost of importing the commodity, $\hat{y}$. Nor can the foreign price, p_0^*, fall below the domestic price expressed in foreign currency, $p_0 - \pi_0$, by more than the foreign currency cost of importing the commodity into the foreign country, $\hat{y}^*$. A similar interpretation would apply to (14) except that the bounds are expressed in terms of export points.

For storeable commodities, the limits on the LOP are affected by the gross return to storage in each country, b or b^*. If the commodity is being stored in each country, the basis is positive (to compensate storers), and one expects the constraint on the LOP to be reasonably tight. But if the basis is negative and little of the commodity is being stored, the deviations from the LOP could be quite large, as is evident in inequalities (13) and (14). We expect deviations to be greater from the spot LOP than from the futures LOP because factors such as production can come into play. Frequently a negative basis implies future output will come on to the market. If such output can be shipped before maturity of the futures contract, the limits on the LOP in the futures market can be narrowed with respect to the limits in the spot market. On the other hand if the negative basis comes simply from a spot shortage without the possibility of future production before maturity of the futures contract, the bounds on both spot and futures LOP will be large.

B. Empirical Results

Summary data for the gross annualized returns to storage, to exporting and to importing from the U.S. perspective are presented in Table 7 along with the implied deviations from the LOP. Silver and copper returns are calculated on the basis of a spot purchase in one country and a forward sale in another. In the other commodities returns are calculated between different futures contracts (generally March and September). The calculations apply to an arbitrager who locks in the returns by purchasing the commodity at the near term futures price in one country and sells the commodity at the more distant futures price in the other country.[20] The time elasped between the time the arbitrager takes delivery and the time he has to make delivery is constant, and it is six months. All arbitrage is between the U.S. and the U.K. Although Table 7 reports means and standard deviations, there is nothing uncertain about any of the returns used in calculating these summary statistics. The standard deviations are merely a measure of the variability in the returns, not a measure of the degree of uncertainty associated with arbitrage. An unprofitable arbitrage opportunity can be rejected in advance.

Silver is a prototype of a well-behaved commodity. The average certain annual return to holding silver in the U.S. over three-month intervals (b) was .0516 per year, while the returns to exporting and importing (x and y) were .0718 and .0500, respectively. (Corresponding numbers from the U.K. perspective, not shown in the table, are larger; $b^* = .1058$, $x^* = .0856$, $y^* = .1074$, and reflect the higher U.K. rate of interest.) There is no incentive to import silver, and the return to exporting net of the domestic storage opportunity (x-b) is only .0203 per year, or $\frac{.0203}{4} = .005$ per arbitrage operation.

Since theory suggests that the arbitrage limits are tighter when the basis is not negative, we also examine gross arbitrage returns for only when the basis is positive. For the three-month holding period for silver a negative basis exists in ten cases. Eliminating these observations raises the U.S. return to storage and exporting but does not affect the net income to exporting. The results for the six-month holding period are in exact accord

Table 7

Mean and Standard Deviations (in parentheses) of Annualized
Certain Gross Returns from Storage and International
Arbitrage, U.S. Perspective

Commodity	Obs.	U.S. Basis $b = p_1 - p_0$	Export $x = p_1^* + \pi_1 - p_0$	Import $y = p_1 - \pi_0 - p_0^*$	Deviation from LOP[c] Futures $x-b= p_1^* + \pi_1 - p_1$	Deviation from LOP[c] Spot $y-b = p_0 - \pi_0 - p_0^*$
Silver: Spot - 3 months						
All	78	.0516	.0718	.0500	.0203	-.0015
		(.0594)	(.0798)	(.0622)	(.0591)	(.0807)
b>0	68	.0644	.0845	.0500	.0200	-.0145
		(.0512)	(.0744)	(.0587)	(.0591)	(.0724)
Silver: Spot - 6 months						
All	64	.0733	.0723	.0703	-.0009	-.0030
		(.0327)	(.0377)	(.0274)	(.0268)	(.0334)
b>0	63	.0749	.0739	.0704	-.0010	.0045
		(.0302)	(.0359)	(.0276)	(.0270)	(.0314)
Copper: Spot - 3 months						
All	47	.1305	.0784	.0863	-.0521	-.0442
		(.8136)	(.8385)	(.1539)	(.1032)	(.9122)
b>0	17	.9380	.9226	-.0225	-.0154	-.9605
		(.8374)	(.8436)	(.1724)	(.1157)	(.9312)
Coffee: March - Sept.						
All	221	-.0365	-.4437	.3273	-.4072	.3637
		(.1582)	(.1601)	(.2576)	(.1562)	(.1780)
b>0	124	.0738	-.4010	.4805	-.4748	.4067
		(.0572)	(.1413)	(.2017)	(.1603)	(.1767)
Cocoa: March - Sept.						
All	283	-.1925	-.1187	-.2752	.0738	-.0827
		(.1381)	(.1550)	(.1634)	(.0548)	(.0775)
b>0	33	.0367	.1161	-.0416	.0795	-.0783
		(.0282)	(.0532)	(.0437)	(.0479)	(.0366)

Table 7, Continued

Commodity	Obs.	U.S. Basis $b = p_1 - p_0$	Export $x = p_1^* + \pi_1 - p_0$	Import $y = p_1 - \pi_0 - p_0^*$	Deviation from LOP[c] Futures $x-b = p_1^* + \pi_1 - p_1$	Deviation from LOP[c] Spot $y-b = p_0 - \pi_0 - p_0^*$
Sugar:[a] March - Sept.						
All	125	-.0379	.1228	-.2632[2]	.1607	-.1958[2]
		(.2269)	(.2648)	(.2187)	(.0599)	(.0911)
b>0	56	.1771	.3736	-.0993[2]	.1965	-.2318
		(.0880)	(.1126)	(.0709)	(.0418)	(.0713)
Soybean meal:[b] June - Dec.						
All	81		.3244	-.3964	.2775	-.3020
			(.0666)	(.1907)	(.0800)	(.0555)
Wheat: March - Sept.						
All	163	.0155	.4444	-.4718	.4290	-.4873
		(.3522)	(.3612)	(.4881)	(.4289)	(.3776)
b>0	69	.3578	.4901	-.1081	.1323	-.4659
		(.2166)	(.4007)	(.3851)	(.3917)	(.4059)

Notes to Table 7:

[a]In sugar, only data for the March futures contract is available in both the U.S. and U.K., although futures price for the exchange rate and the U.S. futures price of sugar are available for both March and September. When September is "near" and March is "far," the arbitrage is to buy U.S. September and sell U.K. March, i.e., export. When March is "near" and September is "far," the arbitrage is to buy U.K. March and sell U.S. September, i.e., import. The exact number of observations for each of these positions is as follows:

	Obs.	Obs. for b>0
Export, x	125	56
Import, y	138	67
x-b	125	56
y-b	138	67

[b]In soybean meal the only contract match is December although U.K. futures prices are available for soybean meal and the exchange rate for June. As a result the U.S. basis cannot be calculated and the results conditioned on b>0 are not obtainable. The results from the U.K. perspective are as follows:

$$b^* = -.0648\ (.1818),\ x^* = -.3668\ (.1892),\ y^* = .3635\ (.0533).$$

[c]Deviations from the LOP are annualized and therefore differ from those reported in Table 2 even when the number of observations is the same.

with the LOP--returns from any perspective are the same, thereby yielding a zero deviation from the LOP.

Some of the remaining commodities are not so well behaved and yield substantial gross returns to arbitrage. In coffee an average gross return of .3273 per year was available to the U.S. importer, and the distribution of returns was such that 118 of 221 observations yielded a return in excess of this average. The importer could have averaged .3637 per year relative to his U.S. storage opportunity, with 115 of 221 cases in excess of this return. Since the import of coffee is assumed to occur over six months, the return per operation is $\frac{.3637}{2}$ or .1818. In sugar, soybean meal and wheat, there existed a substantial average gross return to the U.S. exporter. For example, in the case of wheat, 95 of 163 cases yielded a return to the exporter in excess of the average return of .4444 per year. In none of the cases, except wheat, did conditioning the returns on a positive U.S. basis narrow the deviation from LOP as we had expected. For wheat the average value of (x-b) falls from .4290 to .1323 when observations with a negative basis are eliminated. This implies that, in all commodities except wheat, changes in b and in x are highly correlated.

The remaining commodities, while not as "well-behaved" as silver, also do not yield substantial returns relative to domestic storage opportunities. In copper all returns are less than U.S. storage opportunities. In cocoa average returns to importing and exporting were negative. Because the U.S. basis was more negative than the return to exporting, a positive net return to exporting appears to exist; but this is not a true opportunity unless the arbitragers could earn the basis, which is not possible. Conditioning cocoa returns on a positive basis yields a net return to exporting of .0795 per year. But there are only 13 of 33 cases in excess of this return, which amounts only to $\frac{.0795}{2} = .0397$ per arbitrage operation, probably insufficient to cover transport costs.

These results indicate that a number of commodities--coffee, sugar, soybean meal, wheat--allow large average gross returns to arbitrage. In the remaining commodities--silver, copper, cocoa--average arbitrage returns in excess of U.S. opportunities are small. We are not prepared to conclude from these results that markets in certain commodities are inefficient, and that they provide large riskless profit opportunities. Instead we are inclined to attribute these gross arbitrage returns to transportation costs, taxes, tariffs and other barriers such as quotas. In addition, some of the arbitrage returns may reflect differences in futures contract definitions and delivery terms.

Constant barriers to arbitrage would imply constant though perhaps high gross riskless returns. From the point of view of PPP such constant gross returns are far less troublesome than highly variable arbitrage returns. Highly variable arbitrage returns imply "looseness" in international price ratios, and they imply that even the most uniform commodity would have different price characteristics in different countries. Such "looseness" in relative prices would call to question one of the crucial assumptions of PPP.

One way to quantify the "looseness" in international relative prices is to calculate a measure of their variability and compare it to a similar measure of variability within one country. One candidate is the ratio of the futures price to the current price of a commodity. We can compare the variability of the futures-to-spot price of a commodity in the U.S. (p_1-p_0) to the variability of the futures price in the U.K. (adjusted by the exchange rate) to the spot price in the U.S. $(p_1^*-\pi_1-p_0)$, and to the variability of the futures prices in the U.S. to the spot price in the U.K. $(p_1+\pi_0-p_0^*)$. These comparisons are shown in Table 7. The relative price of futures-to-spot is the U.S. basis, while the ratio of futures prices in the U.K. to spot prices in the U.S. is x.

If there is no appreciable "looseness" in international relative prices and the LOP works well (adjusted for constant barriers) then the variance of the basis (b) would not be significantly different than that of the ex-post returns (x). The F-statistic indicates that only in the case of silver and copper we cannot reject the hypothesis that the variances are not different at the 5-percent level.[21] For coffee, cocoa and wheat the difference is significant at the 1-percent level while for sugar it is significant at the 5-percent level. Similarly, comparing the basis to the import returns shows that, except for silver, the hypothesis that the variances are not different is rejected at the 1-percent level.

The results of this test confirm and extend conclusions reached from analyzing arbitrage returns. There appear to be significant gross returns to arbitrage. Furthermore, these gross returns do not appear to be exclusively a result of constant barriers, since constant barriers would have no effect on the variability of relative prices. Rather, the gross returns are more likely to be a result of transactions costs. These transactions costs allow relative prices of the same good to behave differently in different countries. On the basis of these rough comparisons, we are not prepared to conclude that the variability of international relative prices is "excessive" as compared to the variability of domestic relative prices. But these results leave open the possibility that sufficient "looseness" exists in the short run LOP to admit factors other than PPP as determinants of the exchange rate in the short run.

IX. Summary and Conclusions:

The law of one price (LOP) as usually stated, and as represented in equation (4) or (5), is a simplification that ignores transaction costs and other impediments to commodity arbitrage. On the basis of weekly data, for narrowly defined commodities traded in futures markets in different countries during the period 1973-1980, initial regression tests reject the simple version of the LOP for some of the commodities studied. However, the evidence suggests that a broader version of the LOP that accounts for transaction costs would not be rejected. While detailed data on transaction costs and other barriers to commodity arbitrage are not available, two pieces of evidence point to the importance of arbitrage costs and to the fundamental tendency of the LOP to be satisfied. First, classification of data by maturity shows that the variance around the LOP declines with the maturity of the futures contracts. This is consistent with the hypothesis that arbitrage costs decline with increases in the planning horizon. Second, use of a dummy variable procedure to classify data in a way that recognizes the existence of arbitrage bands produces an impressive improvement in the regression results in the sense that the regression slope coefficient moves closer to the theoretical value of unity, and the serial correlation of the residuals is reduced. Considerable additional improvement undoubtedly can be achieved if the classification procedure, which was uniform across commodities, takes account of the impediments to arbitrage in the individual commodities for which systematic deviations from the LOP remain or if the adjustment mechanism is otherwise more completely specified. We are thus not willing to reject the Law of One Price, appropriately adjusted for transaction costs, as a systematic tendency.

While the LOP may hold as a systematic tendency, the size and persistence of short run deviations from the LOP are important to the validity of PPP as a model of short run exchange rate determination. If the international relationship of even commodity prices is "loose" because of transaction costs or other factors, there may be sufficient slack in the short run behavior of prices to admit determinants of the exchange rate other than PPP. An analysis of the residuals from the LOP relationship reveals that significant serial correlation of the deviations from the LOP exists in all commodities, while contemporaneous correlations of these deviations across commodities are generally small. This implies that deviations are commodity specific rather than due to omitted macro-economic factors. It also suggests that relative price changes, not permissible under the simple purchasing power parity theory of exchange rate determination, arise.

The existence of futures markets permits an arbitrager to lock in a certain return from purchasing the commodity in one country and selling it at a later date in another country. While gross arbitrage returns calculated in this way sometimes prove to be quite large, we are not willing to conclude on the basis of this evidence alone that international commodity markets are necessarily inefficient or that arbitrage fails to take place. These returns may be explained by large costs of arbitrage and other impediments to arbitrage.

Appendix A: Data

The data used in this study are summarized in Table A which is largely self-explanatory.

In the U.K., all the metals are traded on the London Metal Exchange (LME), and spot and forward prices are available. In the U.S., silver and copper are traded on a futures market, but no futures prices exist for tin, lead and zinc. Even where futures prices exist, as in copper, maturities do not always match forward maturities, which results in a reduction in the sample size.

Care was taken to control for units of measurement. In general, U.K. commodity prices are quoted in pounds per metric ton while U.S. prices are generally quoted in cents per pound. Only wheat created some difficulties since the U.K. measure, long tons, is a weight measure whereas the U.S. measure, bushels, is a volume measure. We converted based on the volume standards required of the U.K. contract. In any event an improper conversion would be reflected in the intercept of our regression tests and would not affect the slope coefficient.

A useful source for information on the world's commodity exchanges is de Keyser (1979).

Appendix Table A

Description of Commodity Price Data

Commodity	Commodity Contract: U.S. or other country	Commodity Contract: U.K.	Period Covered	Data[a] Source
Silver	U.S. spot	spot	1/5/72-5/28/80	Samuel Montagu
Silver	U.S. futures: various Comex cents/lb	forward: 3,6 mos LME £/metric ton	1/5/72-5/28/80	JC
Copper	U.S. spot	spot	1/5/72-7/30/80	JC
Copper	U.S. futures: various Comex cents/lb	forward: 3 mos LME £/metric ton	12/6/72-6/27/79	JC
Tin	U.S. spot	spot	1/5/72-7/30/80	JC
Lead	U.S. spot	spot	1/5/72-7/30/80	JC
Zinc	U.S. spot	spot	1/5/72-7/30/80	JC
Coffee	U.S. futures: March, Sept. NY Coffee & Sug. Exch. Coffee "C", arabica cents/lb	futures: March, Sept. Coffee Terminal Mkt. Robusta £/long ton prior to 2/20/74 £/metric ton as of 2/20/74	10/4/72-6/27/79	CSFM
Cocoa	U.S. futures: March, Sept. Dec. NY Cocoa Exch. cocoa beans cents/lb	futures: March, Sept., Dec. London Cocoa Terminal Mkt. Assoc. cocoa beans £/metric ton	5/17/72-6/27/79	CSFM
Sugar	U.S. futures: March, Sept. NY Coffee & Sug. Exch. #11 sugar cents/lb	futures: March United Terminal Sugar Mkt Assoc raw sugar £/metric ton	4/5/72-2/28/79	JC

Appendix Table A, continued

Commodity	Commodity Contract: U.S. or other country	Commodity Contract: U.K.	Period Covered	Data[a] Source
Soybean	U.S. futures: Dec. Chicago Board of Trade soybean meal dollars/short ton	futures: Dec., June London Soybean Meal Futures Mkt. toasted extracted soybean meal £/metric ton	1/8/75-12/26/79	JC
Wheat	U.S. futures: March, Sept. Chicago Board of Trade #2 Soft red dollars/bushel	futures: March, Sept. London Grain Futures Market EEC Wheat, weight to exceed 72.5 kg per hectolitre £/long ton	4/2/75-9/19/79	JC
Rubber	Malaya spot	spot	1/2/74-12/26/79	LFT
Greasy Wood	Australia spot	spot	1/2/74-12/26/79	LFT
British pound	U.S. spot futures: Mar., Sept., Dec.		1/5/72-7/30/80 1/5/72-7/30/80	JC CSFM
Australian$		spot	1/2/74-12/26/79	LFT
Malaysian ringat		spot	1/2/74-12/26/79	LFT

[a]Abbreviations: JC = Journal of Commerce. CSFM = Columbia Center for Study of Futures Market. LFT = London Financial Times.

Appendix Table B
Regression Statistics
$\Delta(p-p^*) = a_0 + a_1 \Delta\pi$

	a_0 (s.e.)	a_1 (s.e.)	r^2 and s.e. of reg.	D.W.	Observations
Silver spot	.0006 (.0010)	.9458 (.1098)	.1514 .0236	2.899	426
Silver 3 months	-.0011 (.0020)	.8739 (.0633)	.7125 .0175	2.394	79
Silver 6 months	-.0008 (.0022)	.8797 (.0659)	.7741 .0160	1.837	63
Copper spot	-.0000 (.0021)	.0297 (.2029)	.0000 (.0438)	2.177	432
Copper 3 months	-.0006 (.0045)	.8906 (.1151)	.5765 .0301	2.547	47
Tin spot	-.0005 (.0015)	.4983 (.1481)	.0259 .0319	2.824	428
Lead spot	-.0007 (.0025)	-.0474 (.2412)	.0001 .0521	2.073	432
Zinc spot	.0001 (.0024)	.2051 (.2263)	.0019 .0489	1.742	432
Coffee (pooled)	-.0001 (.0013)	.5182 (.1090)	.0467 .0283	2.340	527
Cocoa (pooled)	.0003 (.0011)	.5782 (.0924)	.0432 .0314	2.543	869
Sugar (pooled)	.0002 (.0023)	.8974 (.0129)	.9404 (.0390)	2.556	307
Soybean meal (pooled)	-.0027 (.0029)	.5912 (.1204)	.1000 (.0417)	2.219	209
Wheat (pooled)	-.0027 (.0018)	.3225 (.1408)	.0145 (.0343)	1.828	371
Rubber	-.0006 (.0017)	.6655 (.1654)	.0584 (.0281)	2.073	279
Wool	-.0001 (.0020)	.5926 (.1103)	.0962 (.0322)	2.525	273

Footnotes

[1]The best known exponent of the theory was Cassel (1918). An excellent review of the literature is in Officer (1976). Much of the literature is conveniently collected in Frenkel and Johnson, eds. (1976) and Frenkel and Johnson, eds. (1978).

[2]Anticipated inflation, for instance, causes no relative price changes, and PPP holds exactly.

[3]Roll also notes the implications of his findings for an international asset pricing model (IAPM). If LOP holds exactly, there is a one-good world and the standard capital asset pricing model of Sharpe (1964) would apply directly. Uncertain changes in relative prices necessitate a distinct IAPM even though the LOP could hold in an expectational sense.

[4]As far as we know two published studies other than Jain's use commodity futures prices. Dominguez (1972) examines the effect of devaluations in the U.K. pound on U.S. and U.K. cocoa prices. Brown (1977) examines arbitrage opportunities between U.S. and U.K. silver futures markets in an interest rate parity framework.

[5]See Cox, Ingersoll and Ross (1981) for a discussion of the valuation of futures and forward contracts.

[6]Where possible U.S. opening and foreign closing prices are used in order to match transactions times as closely as possible.

[7]No studies go so far as to test whether $\sigma^2(\tilde{u}) = 0$, something which would be expected if commodity arbitrage were perfect. Given the stochastic nature of $\tilde{u}$, the null hypothesis should not necessarily include $\alpha_0 = 0.0$ since the value of α_0 depends on the distribution of $\tilde{u}$. For example if $\tilde{u}$ is lognormal, α_0 equals $-\frac{1}{2}\sigma^2(\tilde{u})$.

[8]See Richardson (1978) or Jain (1980), for example.

[9]The bias in the estimate of α_1, $\hat{a}_1$, is larger the larger the value of m relative to the variability of π. Disturbances and measurement errors arising in p or p^* cause no bias in estimates of a_1 so long as π is exogenous. The residuals in (5) would, however, come from a truncated distribution and would not be exactly normal.

[10]Examining the deviations from LOP at the levels gives essentially the same results. We report the results for the logs because they are directly comparable to the regression results reported below.

[11]On the assumption that the residuals follow a first order serial correlation with coefficient ρ and all the remaining assumptions of the regression model are satisfied,

$$\text{var}(\hat{a}_1) = \frac{1+\rho^2}{1-\rho^2} s^2(\hat{a}_1) ,$$

where $s^2(\hat{a}_1)$ is the estimated variance and $\text{var}(\hat{a}_1)$ is the true variance under the above assumptions. Thus if $\rho = .8$, the correct standard error is

$$\left[\frac{1+.64}{1-.54} \right]^{1/2} = 2.13$$

times larger than the calculated standard error.

[12]Jain (1980) reaches overly pessimistic conclusions about the validity of the LOP because he relies on various differencing procedures.

[13]In the case of cocoa, which has three futures contracts, we chose to create the "Near" and "Far" series only from the March and September contracts, in order to maintain comparability with the other Near and Far series. Use of the December contract as well to create Near and Far series, while producing a greater difference in time to maturity of the two series, gave empirical results that were no different.

[14]To illustrate the effect on the DW statistic of infrequent switches from one arbitrage band to the other consider a case in which half the observations lie on the upper band and half lie on the lower band, and assume there is only one switch from the lower band to the upper band. Assume the width of the band is 2m as in Figure 1 and assume there are 100 observations. Given the definition of the DW statistic as

$$DW = \frac{\sum_{t=2}^{n} (Z_t - Z_{t-1})^2}{\sum_{t=1}^{n} Z_t^2},$$

where Z_t is the residual, that information implies $DW = \frac{4m^2}{100m^2} = .04$.

[15]For example, in sugar, soybean meal and wheat almost all values of $(p-p^*-\pi)$ are negative while in coffee almost all values of $(p-p^*-\pi)$ are positive.

[16]Regressions using D_1 and D_2 as slope dummies were also estimated, but that step did not produce a significant reduction in the standard error of the regression.

[17]The standard error for the first order serial correlation coefficient is calculated under the null hypothesis that there is no serial correlation. If that hypothesis is rejected, subsequent standard errors cannot be calculated under the same null hypothesis since the value of the standard error at lag k will depend on the serial correlations at lags $i<k$. We use Barlett's approximation, as reported in Nelson (1973), to calculate the standard error at lag k, s_k:

$$s_k = \frac{1}{\sqrt{n_k}} \left(1 + 2 \sum_{i=1}^{k-1} r_i^2\right)^{1/2}, \quad i < k,$$

where

r_i = auto-correlation coefficient at lag i,

n_k = number of observations used to calculate r_k.

[18]The careful reader will note we do not allow each arbitrager to store the commodity wholly in the other country. We believe this is somewhat unrealistic, but more important, allowing it would not change our conclusions so long as the barriers to trade in the commodity are less than the barriers to direct investment in storage activities in another country. The assumption implies that

$$b \neq b^* + \pi_1 - \pi_0$$

[19]Roll (1979) bases his tests of PPP on the arbitrage through time and space in the absence of futures markets. He defines an uncertain rate of return,

$$\tilde{R} = \tilde{p}^*_s + \tilde{\pi}_s - p$$

where the $\tilde{p}^*_s$ and $\tilde{\pi}_s$ are the uncertain future foreign spot price of the commodity and of the foreign currency, respectively. He argues that in an efficient market $E(R|G) = 0$, where G is the information set at the time the spot purchase is made at price, p. But as he notes later that condition implies, quite unrealistically, that $\hat{x} = 0$. His tests also involve (a) the use of ex post realized prices, not futures prices, and (b) the use of aggregate price indices not well suited to the commodity arbitrage model he establishes. Unlike the returns Roll calculates, our returns are not uncertain. In addition, the narrowly defined commodities we analyze are much more appropriate vehicles for commodity arbitrage.

[20]For example, the return to importing coffee (for which March and September futures prices are available) is calculated as follows. If March is the nearby contract, the (U.S.) arbitrager buys March coffee futures in the U.K., and covers the foreign exchange exposure with a March currency futures contract. He simultaneously sells September coffee futures in the U.S. We assume the arbitrager takes delivery in the U.K. on his March futures

contracts and subsequently makes delivery in the U.S. on his September contract, but the return will also be realized if the futures prices move in the anticipated direction before March. If September is the nearby contract, the return to importing is achieved by buying U.K. coffee futures, covering the foreign exchange exposure, and selling March coffee futures in the U.S.

[21] Soybeans are excluded from this calculation since we have only one contract per year for the U.S. The F-test is constructed for the subsample of relative prices conditioned on $b>0$. The reason for the restriction is that $b<0$ is prima facia evidence that storage is not taking place and the postulated arbitrage is inoperative.

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