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Empirically Testing the Law of One Price in an International Commodity Market: A Rational Expectations Application to the Natural Rubber Market

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Abstract

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The Law of One Price (LOP) is an important ingredient in theories of international trade and exchange rate determination. An important shortcoming of the existing empirical literature is that parity is typically assumed to hold contemporaneously. This overlooks the fact that international commodity arbitrage takes place over time as well as across spatially separated markets. Recognizing this fact, we expect to see parity holding for expected prices. A model which incorporates the expectations of commodity arbitragers is constructed and used to test the LOP in the natural rubber market. Results indicate that the inclusion of expectations may be of value when considering the LOP.

Introduction

The Law of One Price (LOP) is an important component in theories of international trade and exchange rate determination. The LOP asserts that foreign commodity prices, once adjusted for exchange rates and transportation costs, will be equal to domestic commodity prices. This equality is established and maintained by the profit seeking actions of international commodity arbitragers. Adherence to the LOP implies efficiency in international commodity markets.

Classical theories regarding the gains from trade and specialized production

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rely upon the efficient determination of a unique terms of trade. When these ideas are extended to consider international trade between monetary economies, a unique terms of trade ensures adherence to the LOP. However, in reality, adherence to the LOP may be constrained by several factors including the exercise of market power in imperfectly competitive markets, physical barriers to trade such as transport costs, and trade limiting governmental policies.

The question of adherence to the conditions for price parity in international commodity markets has received a great deal of attention in the empirical international trade literature. The results differ as to degree, but most empirical evidence concludes in favor of rejecting adherence to the LOP theory. Many recent investigations have indicated that deviations from parity conditions are common in the short run but that parity is often found to hold in the long run. In this light, Kravis and Lipsey (1978) conclude that markets may function in the 'textbook' fashion but slowly rather than instantaneously. Isard (1977) argues that exchange rate changes substantially alter the dollar-equivalent prices for most narrowly defined goods and that these relative price effects seem to persist for several years. Crouhy-Veyrac et al. (1982) attribute short run deviations to transfer and transaction costs. Protopapadakis and Stoll (1983) also point to transport costs and other impediments to international commodity arbitrage as reasons for short run failure of the LOP. Using a model which distinguishes between long-run and short-run prices, Protopapadakis and Stoll (1986) obtain results which indicate that the LOP almost never holds in the short run but that the long run LOP receives strong support.

An important shortcoming of the existing empirical literature addressing the LOP question is that such analyses have typically assumed that parity should hold contemporaneously. This approach overlooks the fact that international commodity arbitrage takes place over time as well as across spatially separated markets. It takes time to move goods from one market to another. Recognizing this fact, we should not expect to see parity holding for contemporaneous prices unless arbitragers have perfect foresight or unless prices are constant. A more reasonable approach would be to expect international commodity arbitragers to act upon the price that they expect to prevail in the market in which they will sell when their goods are delivered. Thus we would instead expect to see parity holding for expected prices.

It is the objective of this paper to incorporate the role of expectations into an empirical investigation of the LOP. The particular application is to the international market in raw natural rubber. Barlow (1978, p. 427) notes that the international market for natural rubber is of a competitive nature with little market power being exhibited by buyers or sellers. Several attributes of the natural rubber market (discussed in detail below) make it especially suited to such an investigation. The investigation makes use of a simultaneous equation structural model of the United States raw rubber industry to generate a rationally expected price. The econometric procedure is related to the theoretical work of Wallis (1980) and combines time series analyses with simultaneous equation estimation techniques. The results of the expectations augmented version of the LOP are compared to a standard formulation of the LOP which utilizes contemporaneous prices.

A model of the Law of One Price

Empirical tests of the Law of One Price are best carried out using prices of primary (non-processed or non-manufactured) commodities. There are three fundamental reasons for the superiority of this approach. First, following the demand for characteristics theory of Lancaster (1966), it is not the goods themselves that are valued but instead the utility bearing attributes of the goods. We would expect goods bearing different attributes, that is differentiated goods, to have different values and thus different prices. A primary commodity is likely to have identical attributes regardless of country of origin or absorption. Secondly, tests utilizing aggregate data may be influenced by the problems associated with indexes and aggregation measurement errors. Tests which use aggregate data to reject the LOP may fail in part due to aggregation and index construction errors. Finally, when tests of the LOP are carried out using highly aggregated price data, there is a high probability that exchange rates will be endogenous to the system used for testing. Such endogeneity will bias the results of any test. The probability that exchange rates will be endogenous is minimized when the tests are carried out using disaggregated primary commodity prices.

Most empirical tests of the LOP utilize a model similar to that of Richardson (1978):

$$P_{it} = \alpha_0 P_{it}^{*\alpha_1} \pi_{it}^{\alpha_2} T_{it}^{\alpha_3} R_{it}^{\alpha_4} \quad (1)$$

where P_{it} is country 1's price of commodity i in time t, P_{it}^* country 2's price of commodity i in time t, π_{12t} is the rate of exchange for currency 2 in terms of currency 1, T_{it} is the transfer and transactions costs of trade in commodity i between countries 1 and 2, R_{it} is the residual reasons for price differences between countries 1 and 2, and α_0, α_1, α_2, α_3, α_4 are parameters.

Strict adherence to the LOP requires that the domestic price of a good, once adjusted for exchange rates, transfer costs, and any differences in quality, will be equal to the foreign price of the good. Should a disparity between these prices be detected by international commodity arbitragers they will actively seek profits by buying the good in the lower priced market and transferring it to the higher priced market, selling it there. Given efficient commodity markets, such actions should continue until prices are equalized between the markets. For a basic homogeneous commodity, this requires that:

$$\alpha_1 = \alpha_2 = \alpha_3 = 1$$
$$\alpha_4 = 0 \qquad (2)$$

Thus equation (1) becomes a statement of the Law of One Price.

A major drawback to this approach is that explicit information about transportation costs is rarely available. This problem has commonly been handled by assuming transfer costs to be constant over the period of study. If transfer costs were truly constant then T_{it} can be removed as a variable in the equation since the analysis is being conducted in a regression framework. Another approach to this problem is to assume that transfer costs can be approximately represented as a constant proportion of nominal product prices. In each case, the influences of transfer costs on commodity prices are reflected in a constant term, which is no longer required to be equal to 1.

For this analysis, the assumption of constantly proportional transfer costs is maintained. It is also assumed that since raw rubber, a basic commodity, is the focus of this study there are no residual reasons for price differences. Thus R_{it} is omitted and treated as an unobserved random disturbance.

The basic shortcoming of the standard approach to testing the LOP is that contemporaneous domestic and foreign prices are utilized in the empirical estimation. This analysis will instead utilize a simple model which attempts to consider the role of expectations. This model relies on several restrictive assumptions. First, it is assumed that the home country is primarily an exporter and the foreign country is primarily an importer of the commodity in question. This allows limiting the consideration of expectations to one side of the exchange. Namely, it is assumed that exporters respond to their expectations of prices as the time of delivery in the foreign market and that this in turn determines the price of the commodity in the domestic market. This assumption seems entirely reasonable for a commodity like natural rubber where Malaysia is the home market and New York is the foreign market. Secondly, it is assumed that the importing country is the largest world consumer of the commodity. This ensures that it is the expected price of the commodity in the importing market that will be of primary importance to the exporters. This assumption is maintained in the natural rubber market for the U.S.A. which is by far the largest consumer of natural rubber in the world. Third, it is assumed that expectations are rational and identical in both markets. This ensures that the foreign price expectations of an exporting agent are shaped and determined by the same structural model and information set that is available to foreign consumers in the import market. Fourth, it is assumed that the physical transfer of rubber can be accomplished in one month. Finally, it is assumed that transactions are denominated in the currency of the importing country. This allows the utilization of contemporaneous exchange rates rather than some expected future exchange rate. This assumption draws support from

Hooper and Kohlhagen's (1978) contentions that U.S. imports are primarily invoiced in dollars.

Under these assumptions, the basic empirical tests of the law of one price conducted in this analysis are specified by the following equations:

$$P_{it} = \beta_0 ({}_tP^{e*}_{it+1})^{\beta_1} (\pi_{12t})^{\beta_2} \tag{3}$$

$$P_{it} = \alpha_0 (P^*_{it})^{\alpha_1} (\pi_{12t})^{\alpha_2} \tag{4}$$

Note that ${}_tP^{e*}_{it+1}$ indicates the expected value of P_i in time $t+1$, as projected in time t. The law of one price is rejected for the standard model when the following hypothesis is rejected:

$$\mathrm{H}_0 \colon \alpha_1 = \alpha_2 = 1 \tag{5}$$

The law of one price is rejected for the expectations augmented model when the following hypothesis is rejected:

$$\mathrm{H}_0 \colon \beta_1 = \beta_2 = 1 \tag{6}$$

The remaining task at hand is the formulation of a mechanism capable of generating a valid rationally expected price.

Formulation of a rationally expected price

The empirical specification is based on a simple model of intertemporal competitive equilibrium with rational expectations. The model is similar to the first type of model analyzed in Muth's (1961) original treatment of rational expectations. The basic model posits supply and demand conditions for imported natural rubber in the U.S.A. Price observations are those taken for a common grade of raw rubber in the New York spot market. The model incorporates both consumption and stock demand components to obtain an overall import demand for natural rubber in the U.S.A. The supply side of the model depends mainly upon the expected price of rubber in the U.S. market. Because the estimation spans a long period of time, an alternative supply specification which includes a quadratic time trend variable is also utilized to capture possible structural shifts that may have occurred over time. Thus the econometric estimation utilizes two alternative structural models which are identical in the demand side but differ in their specification of the supply of imported rubber.

Consider the following model:

– consumption demand:

$$Q^{\mathrm{d}}_{\mathrm{ct}} = \delta_0 + \delta_1 P_t + \delta_2\, \mathrm{PS_t} + \delta_3 \mathrm{y}_t + \mathrm{u}_{1t} \tag{7}$$

– desired stocks:

$$Q^*_{\mathrm{st}} = \gamma_1 ({}_{t-1}P^{\mathrm{e}}_t - P_{t-1}) + u_{2t} \tag{8}$$

– import supply (a):

$$Q^{s}_{ta} = \theta_0 + \theta_1 \, {}_{t-1}P^{e}_{t} + u_{3at} \tag{9a}$$

– import supply (b):

$$Q^{s}_{tb} = \theta_0 + \theta_1 \, {}_{t-1}P^{e}_{t} + \theta_2 \, \text{TIME} + \theta_3 \, \text{TIME}^2 + u_{3bt} \tag{9b}$$

– equilibrium (a):

$$Q^{d}_{ct} + Q^{*}_{st} - \lambda S_{t-1} = Q^{d}_{t} = Q^{s}_{ta} \tag{10a}$$

– equilibrium (b):

$$Q^{d}_{ct} + Q^{*}_{st} + \theta S_{t-1} = Q^{d}_{t} = Q^{s}_{tb} \tag{10b}$$

where P_t is the price of natural rubber in time t, ${}_{t-1}P^{e}_{t}$ is the expected price of rubber in time t, as projected in time $t-1$, PS_t is the price of a substitute product in time t, Q^{d}_{ct} is the quantity of rubber demanded for consumption in time t, Q^{*}_{st} is the desired level of rubber stocks in time t, $Q^{s}_{t\alpha}$ is the quantity of rubber supplied in time t (for $\alpha = a, b$), y_t is income in time t, P_{t-1} is the price of natural rubber in time $t-1$, TIME is a time trend variable, S_{t-1} is natural rubber stocks, time $t-1$, and u_{1t}, u_{2t}, u_{3at}, u_{3bt} are random disturbances with expected values equal to zero. Note that the desired level of rubber stocks is assumed to be a function of the difference in the price expected to prevail in t, as projected from time $t-1$, and the actual price in $t-1$. It is best to consider this component of demand to be a demand for buffer stocks. It arises as a result of the actions of commodity traders who are hedging against potential demand shocks in period t. While it may be theoretically more tractable to consider this component of demand to depend upon expectations of future period prices, it adds significantly to the complexity of the problem by adding higher order differences to the equations of the system. It will be assumed that the present specification is sufficient to model the actions of international commodity traders and domestic U.S. consumers.

Following the format of Wallis (1980), the model can be written in standard matrix form as:

$$\boldsymbol{B}\boldsymbol{Y}_t + \boldsymbol{A}\boldsymbol{Y}^{e}_{t} + \boldsymbol{\Gamma}_{\alpha}\boldsymbol{X}_{\alpha t} = \boldsymbol{U}_t \qquad \text{for} \quad \alpha = a, b \tag{11}$$

An expression for the expected values of the endogenous variables can then be obtained by taking the conditional expectation (E_{t-1}) of the reduced form of equation (11) and solving for Y^{e}_{t}:

$$\boldsymbol{Y}^{e}_{t} = -(\boldsymbol{B}+\boldsymbol{A})^{-1}\boldsymbol{\Gamma}_{\alpha} \, \boldsymbol{E}_{t-1}(\boldsymbol{X}_{\alpha t}) \tag{12}$$

This gives the expected value of natural rubber prices as a function of the parameters of the structural model and forecasts of the exogenous variables. This expression summarizes the information given in equations (7)–(10b). Detailed discussions regarding the solution of rational expectations models of this type can be found in Wallis (1980) and Goodwin and Sheffrin (1983).

In order to empirically estimate the model, a forecasting rule must be specified to generate expectations of the exogenous variables. In this application it is assumed that such expectations can be accurately represented by appropriately specified time series models. Such an approach has been suggested by Nerlove et al. (1979) in their "quasi-rational expectations" formulation. This procedure implicitly treats the time series forecasts as data and thus treats the time series models as maintained hypotheses in the estimation of a rationally expected price.

Discussion of data

The data used in this study are meant to represent observations on conceptually relevant market data for a freely traded basic homogeneous commodity. The special application of a rational expectations model as it is utilized in this analysis required a commodity for which the foreign country is primarily an importer and the home country is primarily an exporter. The natural rubber market was especially suited to such an analysis. The home market is defined to be Malaysia and the foreign market is defined to be the U.S.A. The basic procedure set forth in this analysis should be applicable, with proper modification, to any internationally traded basic commodity. The natural rubber market was chosen because of the existence of a large data set as well as for its adherence to the criteria set forth in this analysis.

The variables considered to be conceptually relevant in shaping the consumption demand for natural rubber in the United States as given by equation (7) included a measure of consumers' income and the price of a substitute product. For income, the seasonally adjusted monthly series on gross personal income as given in the U.S. Department of Commerce's *Survey of Current Business* (USDC, various issues) was used. The primary product which can be considered to be a substitute in consumption for natural rubber is synthetic rubber. Synthetic rubber is typically derived from the process of polymerization of the hydrocarbons found in crude oil and natural gases (Barlow, 1978). Because a valid data series of synthetic rubber prices was not available, the monthly prices of crude petroleum oil at U.S. domestic wells was used as a proxy for the price of a substitute good. This implicitly assumes that movements in the price of synthetic rubber can be accurately represented by movements in the price of petroleum. The particular series of crude petroleum used in this analysis was obtained from the U.S. Department of Labor's *Producer Price Indexes* (USDL, various issues).

The observations on natural rubber prices were monthly average spot prices of ribbed smoked sheets of grade-1 rubber (RSS-1) as quoted in the Kuala Lumpur (ringitts per metric tonne) and New York (cents per pound) spot markets. The Malaysian series of prices were available from January 1977 through December 1984 and were taken from the FAO *Monthly Bulletin of*

Statistics (FAO, various issues). The New York price series was taken from the *Producer Price Indexes* and covered the period of January 1970 through December 1984. The New York price series had three missing observations which were proxied by the predicted values from a regression on lagged prices and U.S. rubber stocks. The rubber stock series was collected from selected issues of the *Commodity Year Book* (Commodity Research Bureau, New York). All variables used to generate the rationally expected New York spot price utilized data covered January 1970 through December 1984 in the hope that a large number of observations would enhance the efficiency and performance of the econometric estimates.

Exchange rate data was collected from the *International Financial Statistics* series (IMF, various issues). The exchange rates used to conduct the LOP tests were monthly averages of Malaysian ringitts per U.S. dollar.

Econometric estimates of the model

The econometric procedures adopted for analysis first require forecasts of the exogenous variables. The income series was found to be nonstationary. Conversion to a stationary series was accomplished by differencing the series over three periods. The final model chosen to generate forecasts of the exogenous income variable was an ARIMA (2,1,2). The crude petroleum price series required a single differencing transformation. Forecasts of the exogenous petroleum price variable were generated with an ARIMA (1,1,1) model. The estimated time series models and relevant statistics are presented in Table 1.

The structural models, given as equations (7) through (10b), were estimated by full information maximum likelihood (FIML) techniques using the form given by equation (11). The estimation was accomplished using the seemingly unrelated nonlinear regression procedure of SAS. The FIML parameter estimates are presented in Table 2.

TABLE 1

ARIMA models used for forecasting exogenous variables[a]

Personal income series (y_t):

$(1-0.310764\,B-0.357371\,B^2)\,\Delta B^3\,y_t=(1+0.975252\,B+0.955765\,B^2)e_t$

Box Pierce $Q=42.27$ $\chi^2_{0.05}(24)=45.558$

Crude petroleum prices (PS_t):

$(1-0.481477\,\text{B})\,\Delta\text{PS}_t=(1-0.011812\,\text{B})e_t$

Box Pierce $Q=40.20$ $\chi^2_{0.05}(24)=45.558$

[a]B is the lag operator and Δ is the differencing operator.

TABLE 2

Maximum likelihood estimates of structural model parameters

Parameters	Estimate	Asymptotic standard error
Model (a)		
Demand		
δ_0	49.547	2.653
δ_1	0.167	0.060
δ_2	0.002	0.003
δ_3	0.001	0.001
λ	0.003	0.006
γ_1	0.193	0.306
Supply		
θ_0	49.029	2.634
θ_1	0.162	0.057
Model (b)		
Demand		
δ_0	39.421	8.400
δ_1	0.162	0.099
δ_2	0.003	0.003
δ_3	0.001	0.002
λep;	−0.050	0.057
γ_1	3.479	2.070
Supply		
θ_0	45.039	2.999
θ_1	−0.012	0.092
θ_2	0.257	0.100
θ_3	−0.001	0.0004

The price-dependent reduced form equations conform to the data very well. However the quantity dependent reduced form equations had a much smaller degree of explanatory power. It should be acknowledged that the price parameters of the consumption demand equations have positive signs. A possible explanation for this lies in the manner in which the demand for stocks influences the demand for imported rubber. Higher expected prices increase the stock demand for rubber. Unless actual realized prices and last period's price expectations sometimes fail to move together, it may be difficult to distinguish price effects on consumption demand from expected price effects on buffer stock demand. Other possible explanations include a high degree of multicollinearity due to the simultaneous presence of actual and forecasted variables in the estimation equations and the possibility of model misspecification. Because the primary goal of this analysis is to obtain reasonable empirical estimates of the rationally expected prices for use in an empirical test of the LOP and not in identifying the individual parameters of the structural model, it is assumed that the estimated structural parameters can be used to generate valid expected price forecasts. However, it should be noted that any empirical test of the LOP based upon such estimates includes the augmenting hypothesis that expectations are correctly specified. Keeping such conditions in mind, the estimated parameters were used in equation (12) to produce forecasts of the expected price of RSS-1 natural rubber in the New York spot market for the period covering January 1977 through December 1984.

Empirically testing the Law of One Price

The empirical tests of the law of one price conducted in this paper involve equations of the form given by (3) and (4). Both versions of the structural model were used to generate conditionally expected prices in the New York spot market which were used in the expectations augmented version of the LOP given by equation (3). Contemporaneous prices were used in equation (4) for purposes of comparison. The equations were converted to a logarithmic linear-in-parameters form for empirical estimation. The estimated parameters for the three versions of the LOP test are presented in Table 3. Model (1) utilizes contemporaneous prices. Models (2) and (3) utilize rationally expected prices as generated by versions (a) and (b) of the structural model, respectively.

TABLE 3

LOP test parameter estimates

Parameter	Estimate	Standard error	t-ratio
Model (1)			
$\ln(\alpha_0)$	0.9804	0.3798	2.582
α_1	0.9144	0.0367	24.914
α_2	0.3975	0.1615	2.461
$R^2=0.9427$	$F=863.338$		
Model (2)			
$\ln(\beta_0)$	0.6675	0.4130	1.616
β_1	0.9405	0.0397	23.710
β_2	0.5561	0.1811	3.071
$R^2=0.9342$	$F=666.801$		
Model (3)			
$\ln(\beta_0)$	0.3191	0.3536	0.903
β_1	0.9774	0.0340	28.686
β_2	0.6618	0.1539	4.301
$R^2=0.9529$	$F=950.441$		

TABLE 4

LOP hypothesis testing results

Model	Hypothesis	Test statistic	Critical value[a]	Result
(1)	H_0: $\alpha_1=1$	F(1, 94) = 5.44	F(1, 100) = 6.90	Fail to reject
	H_0: $\alpha_2=1$	F(1, 94) = 13.91	F(1, 100) = 6.90	Reject
	H_0: $\alpha_1=\alpha_2=1$	F(2, 94) = 7.96	F(2, 100) = 4.82	Reject
(2)	H_0: $\beta_1=1$	F(1, 94) = 2.25	F(1, 100) = 6.90	Fail to reject
	H_0: $\beta_2=1$	F(1, 94) = 6.01	F(1, 100) = 6.90	Fail to reject
	H_0: $\beta_1=\beta_2=1$	F(2, 94) = 3.36	F(2, 100) = 4.82	Fail to reject
(3)	H_0: $\beta_1=1$	F(1, 94) = 0.44	F(1, 100) = 6.90	Fail to reject
	H_0: $\beta_2=1$	F(1, 94) = 4.83	F(1, 100) = 6.90	Fail to reject
	H_0: $\beta_1=\beta_2=1$	F(2, 94) = 4.29	F(2, 100) = 4.82	Fail to reject

[a]Critical values are at the 1% level of significance.

The results of the formal hypothesis testing are presented in Table 4. These tests were conducted by imposing the constraints suggested by equations (5) and (6) and comparing the sum of squared errors from the restricted models to those of the unconstrained models in an ordinary F-test. The tests were conducted for the whole model and for each parameter separately.

None of the models appear to be perversely at odds with the LOP. This is especially true when only the price component is considered. However, note that the coefficients of the expectations-augmented versions of the LOP are closer to one in numerical value. The formal test of the LOP as expressed by H_0: $\beta_1=\beta_2=1$, is maintained for each of the expectations-augmented versions of the LOP while it is rejected for the version using contemporaneous price observations. Model (3) seems to perform especially well and offers strong support for contentions that price parity is much more likely to be observed when expectations are considered in that its price coefficient has a value of 0.977 as compared to the contemporaneous price version's coefficient of 0.914. The major breakdown in the LOP observed in all models arises in the exchange rate coefficient. It appears that exchange rate shocks are only partially reflected in price changes. The implications of this are unclear. It may suggest that transactions are not converted from one currency to another at the time of shipment but instead at the time of delivery. In this case the relevant exchange rate variable may be an expected exchange rate for time $t+1$. Thus a useful extension of the present analysis may include using time series analysis or other forecasting techniques to generate an expected exchange rate variable for use in tests of the LOP.

Concluding remarks

This paper has considered the law of one price in the international natural rubber market. Preliminary results indicate that the inclusion of the expectations of arbitragers may be of some value when considering the LOP. In particular, empirical tests utilizing both contemporaneous and expected prices seem to indicate that expected prices show a stronger adherence to the LOP.

The question of adherence to the LOP has important implications for the appropriate approach to theoretical and empirical modeling of international trade. This is of particular importance in analyses of international agricultural trade where markets are often competitive and commodities are generally of a homogeneous nature and thus are likely to conform to the conditions for price parity. A common approach in applied trade modeling is to assume adherence to the LOP in absolute terms. The results of this study may suggest alternative approaches which explicitly recognize the role of price expectations and delivery lags.

Although the results of this analysis indicate that expectations play an important role in international price linkages, it should not be concluded that the results of the statistical test of the expectations augmented models are necessarily robust. Any test of the LOP based upon an expectations model is implicitly a joint test of the LOP and of the mechanism utilized to generate expected prices. Future work may benefit from considering alternative expectations formation specifications. It would also be of interest to incorporate expected future exchange rates and to consider parity between expected prices in both markets.

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