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by

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ARBITRAGE CONDITIONS, INTEREST RATES, AND INTERTEMPORAL
COMMODITY PRICE RELATIONSHIPS

by

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Recent studies have presented different views on the relationship between interest rates and commodity prices. The theory of storage and arbitrage approaches fully incorporate nominal interest rates in commodity price spreads. Alternative frameworks admit a relationship between the interest rate and commodity own rates of interest and, as a result, the commodity price spread would not completely incorporate the nominal interest rate. The various views on interest rate-commodity price relationships, the potential role of nonneutralities, and existing empirical evidence are examined.

Keywords: Theory of storage, arbitrage, interest rates, commodity own rates, risk premium, nonneutralities
Over the last decade, many studies have examined the relationship between interest rates and commodity prices. Most studies are based on, and support, the theory of storage approach. Under a strict interpretation, the theory of storage indicates that the difference between simultaneously quoted prices for contracts of different delivery dates completely incorporates nominal interest costs. Recently, however, a different view has been advanced suggesting that the commodity own rate—an implicit rate of return to commodities—is related to the real interest rate and, as a result, the far-near commodity price spread would not incorporate the full nominal interest cost.

These interest rate-commodity price relationships deserve further attention for several reasons. First, the relationships serve as a key component in examinations of macroeconomic linkages to primary commodity sectors such as agriculture (Rausser, 19__). Second, they are important for examining nonneutral monetary impacts. That is, with money neutrality, nominal money supply changes would produce no real economic impacts, only nominal price effects. With nonneutralities, changes in the real interest rate will be associated with real price effects, particularly for primary commodities. So, examinations of the importance of real interest rates in the determination of commodity futures prices can provide important information on nonneutral monetary impacts. Third, and at a more institutional level, the relationships explain the direct linkages between financial markets and commodity markets.
II. THEORETICAL RELATIONSHIPS

The literature on the relationship between commodity prices and interest rates has an extensive history. For example, Keynes (19__ and 1936) examined futures prices and the relationship between commodity prices, commodity own rates, and the money rate of interest in detail. Many of these relationships have also been used in a well developed literature on the "theory of storage" [see Working (1949) and, for more recent reviews, Peck (1985), French (1986), or Fama and French (1987)]. As Fama and French (1987, p.55) point out,

"There are two popular views of commodity futures prices. The theory of storage . . . explains the difference between contemporaneous spot and futures prices in terms of interest foregone in storing a commodity, warehousing costs, and a convenience yield on inventory. The alternative view splits a futures price into an expected risk premium and a forecast of a future spot price."

The theory of storage approach is the basis of the arbitrage or interest parity approach used by Frankel (1984 and 1986) and examined in Kitchen and Denbaly (1987). Kitchen and Denbaly (19__) and Fama and French (1987) use essentially identical approaches and present results that support the theory of storage and arbitrage view.

According to Fama and French (1987, p. 55), "the theory of storage is not controversial." However, in a dynamic world of uncertainty, Working's (1949) theory of storage is, in essence, a self-contained but static formulation of intertemporal price relationships. The conceptual inconsistency in Working's (1949) hypothesis was demonstrated long ago by Weymar (1966) who used Muth's
rational expectation hypothesis to show that the spread between future prices for two different dates of delivery should depend on expected stocks, not stocks already in existence.¹

Contrary to the results and interpretation presented in the above studies and, in particular, contrary to a strict interpretation of the view of Fama and French (1987), there does in fact appear to be some controversy about whether the far-near commodity price spread exactly incorporates the nominal interest rate. Cornell and French (1986) report empirical results suggesting that, in response to money shocks, commodity price spreads (the commodity basis) adjust by an amount that is less than the adjustment in the nominal interest rate. The theory that Cornell and French (1986) present indicates that this smaller adjustment of the commodity basis is due to the relationship between commodity own rates and the real rate of money interest. Gordon (1987) introduces similar concerns when he suggests that the convenience yield is related to the nominal interest rate.

A general formulation, which admits a host of special cases, presents the basis or price spreads as

\[
\ln F(t, t + j) - \ln S(t) = \alpha_1 i(t, j) + \alpha_2 sc(t, j) \\
+ \alpha_3 cy(t, j) + \alpha_4 p(t, j) \\
+ \alpha_5 k(t, j) + \alpha_6 ar(t, j)
\]

where \(\ln\) represents the natural logarithm; \(F(t, t + j)\) is the futures contract price in period \(t\) for a commodity to be delivered in period \(t + j\); \(S(t)\) is the spot price in period \(t\); \(i(t, j)\) is the \(j\)th period nominal rate of interest in period \(t\); \(sc(t, j)\) is the \(j\)th period physical storage cost in period \(t\); \(cy(t, j)\) is the \(j\)th period convenience yield in period \(t\); \(p(t, j)\) is the \(j\)th period risk premium in period \(t\); \(k(t, j)\) is the \(j\)th period commodity own rate of
interest in period \( t \); and \( r(t, j) \) is the \( j \)th period arbitrage cost in period \( t \). The parameters \( \alpha_1, \ldots, \alpha_6 \) assume one of two settings, zero or one, depending on the specifications of each alternative case.

In the arbitrage studies conducted by Frankel (1985), the general formulation is simplified by setting \( \alpha_1, \alpha_2 = 0 \) and \( \alpha_3 = \alpha_4 = \alpha_5 = \alpha_6 = 0 \) or

\[
\ln F(t, t + j) - \ln S(t) = i(t, j) + sc(t, j).
\]

This formulation suppresses the convenience yield and potential risk premium components in \( F(t, t + j) \). Frankel's (1985) work concentrates on the expected change in the commodity price (thus replacing \( F(t, t + j) \) with \( E_t S(t + j) \) where \( E_t \) represents the rational expectation formed in period \( t \)). In this setting, the nominal interest cost would be completely reflected in the contracted commodity price change.

An alternative view addressed by Fama and French (1987) splits the futures price into the expected spot price change plus a risk premium associated with price uncertainty, \( p(t, j) = \ln F(t, t + j) - \ln E_t S(t + j) \), and can be presented as

\[
\ln F(t, t + j) - \ln S(t) = \ln E_t S(t + j) - \ln S(t) + p(t, j).
\]

For this formulation, \( \alpha_4 = 1 \) as does \( \alpha_1, \alpha_2, \) and \( \alpha_3 \) with \( \alpha_5 = \alpha_6 = 0 \). Fama and French (1987) examine (3) in detail and find that there is great variation in the relationships across commodities. For example, in the case of agricultural and animal product commodities, futures prices have forecast power for subsequent spot prices while, for precious metals, there is little forecast power. The relationship between the risk premium and futures prices is also highly variable across commodities. For some commodities, futures price variation is related to variation in the premium while, for others (particularly
precious metals), there is no evidence of futures prices being related to
time-varying premiums. Fama and French (1987) also present some marginal evi-
dence that the premium is nonzero on average and interpret this result as con-
sistent with the "normal backwardation" in futures prices suggested by Keynes
(19__)_. That is, with normal backwardation, the premium in (3) would tend to
be less than zero, p(t, j) < 0, and futures prices would be downward-biased
predictors of subsequent spot prices.3

Keynes (1936, pp. 226-27) carefully examined the various components of the
returns to commodities as revealed in the commodity own rate of interest and
in the commodity rate of money interest [these rates are apparently, respec-
tively, the real and nominal rates of interest in commodity markets referred
to by Telser (1986, p. S14)]:

"It follows that the total return expected from the ownership of
an asset over a period is equal to its yield minus its carrying
cost plus its liquidity premium, i.e. to q - c + 1. That is to
say, q - c + 1 is the own-rate of interest of any commodity,
where q, c, and l are measured in terms of itself as stan-
ard. ... To determine the relationships between the expected
returns on different types of assets which are consistent with
equilibrium, we must also know what the changes in relative
values during the [period] are expected to be."

The commodity own rate examined by Cornell and French (1986) is, there-
fore, not a new idea. However, the concept of the commodity own rate as being
related to, even determining, the real interest rate in the economy is new.
In our notation, the Cornell and French (1986) own rate approach sets \( \alpha_1 = \alpha_5 = 1 \) and \( \alpha_2 = \alpha_3 = \alpha_4 = \alpha_6 = 0 \), i.e.,
(4) \[ \ln F(t, t + j) - \ln S(t) = i(t, j) - k(t, j). \]

Cornell and French (1986) show, in theory, that the real interest rate in the economy is a weighted average of the \(k(t, j)\) terms across commodities (weighted by the commodity expenditure share). Their analysis concentrates on commodity own rates as a measure of the real interest rate and the far-near commodity price spread (the commodity basis) as a measure of inflation--the expected change in the value of commodities relative to money.

The difference between the Cornell and French (1986) view and the strict theory of storage and arbitrage views presented above centers on the fact that the arbitrage and theory of storage approaches assume that, in addition to the inflation component of the nominal interest rate, the real interest rate is also completely incorporated in the far-near commodity price spread. From (2) and (4), we see that

(5) \[ k(t, j) = sc(t, j) + cy(t, j). \]

Cornell and French (1986) see a relationship between these components and the real rate of interest, while the strict theory of storage approach does not. Keynes (1936, p. 226) apparently had similar ideas, but the exact interpretation is a bit ambiguous:

"It is characteristic . . . of a stock of liquid goods or of surplus laid-up instrumental or consumption capital that it should incur a carrying cost in terms of itself without any yield to set off against it, the liquidity premium in this case also being usually negligible as soon as stocks exceed a moderate level, though capable of being significant in special circumstances. Different commodities may, indeed, have differing degrees of liquidity-premium amongst themselves . . ."
Very little reason exists here for a relation between commodity own rates and the real interest rate. However, Keynes (1936) did not make clear what was meant by "usually negligible" or "special circumstances," so the potential exists to interpret the liquidity premiums for commodities and money as being related. Additionally, and somewhat at odds with Keynes' (1936) views, commodities could carry an implicit yield. This is apparently the view of Cornell and French (1986) where the own rate is defined as the rate for exchanging current consumption of a commodity for future consumption of that commodity.

So we are left with two different interpretations: the Cornell and French (1986) and Gordon (1987) views in which commodity own rates (liquidity premiums, convenience yields, carrying costs, risk premiums) are related to the real interest rate and the alternative view from the theory of storage and the Frankel (1984) arbitrage studies where commodity liquidity premiums and convenience yields are commodity specific and unrelated to the interest rate (and there is no implicit yield to commodities)--that is, own rates that are unrelated to the real interest rate.

III. EMPIRICAL EVIDENCE IN THE RECENT LITERATURE: INTERPRETATION

The empirical results of Cornell and French (1986) show that, in response to money shocks during the 1980-1982 period, the nominal interest rate change was greater than the change in the far-near commodity spread (the commodity basis). One could argue that such a result provides sufficient evidence to refute the view that commodity own rates and the nominal interest rate are unrelated. However, there are some potential problems with the empirical work and interpretation in Cornell and French (1986) which casts some doubt on the
validity of their view. In particular, they abstracted from transactions costs and nonneutralities.

As discussed in Protopapadakis and Stoll (1983 and 1984), transactions (and other arbitrage) costs can lead to problems and potential bias in estimating parameters based on arbitrage relations. From the perspective of the Frankel (19___) arbitrage relation and its application to the money announcement phenomenon, the arbitrage is from the money market to commodity markets. As a result of the money stock announcement, there is a shock to the market expectation of current and future money stock levels. The shock is exogenous and produces a response of the interest rate and, through simultaneities such as the arbitrage and theory of storage relations, also leads to a change in the far-near commodity price spread.

If the cost of arbitrage represented in (1) on a percentage basis as ar(t, j) between the two markets is substantial, however, there may be little or no profit incentive to produce the equivalent response in the commodity market. To see this, note the relationships in the following presentation—which closely follows the Protopapadakis and Stoll (1983) exposition. Begin with a case where the commodity-financial arbitrage relation holds, as at point X in Figure 1. The announcement of a larger than expected money stock is made, and the interest rate is driven up. Note that the cost of arbitrage is measured here in percent terms. If the change in the interest rate does not exceed the cost of arbitrage, then no profit incentive would exist to change the commodity price spread, producing a point such as Y. Or suppose the initial position was inside the arbitrage bands (for example, point X or Y) and that the change in the interest rate was relatively large, thus producing a commodity price response (a change to point Z, for example). Again, the commodity price spread response would be less than the interest rate response.
\[ \ln(F-S) \]

**Figure 1**

*ARBITRAGE COST*
As a result, unless all observed points exist along one arbitrage band or the other, we would expect to see changes in the commodity price spread to be less than the changes in the interest rate. This is exactly the empirical result observed by Cornell and French (1986).

Cornell and French (1986) also did not address the issue of nonneutral monetary impacts—nonneutralities were assumed away (see Cornell and French, 1986, p. 9, note 7). Frankel and Hardouvelis (1985) discuss the importance of nonneutralities in great detail and show that the commodity price response to money announcements is consistent with such an interpretation. Factors that drive real interest rate changes also drive real primary commodity price changes.

Frankel and Hardouvelis (1985) showed that, in response to the announcement of a larger than anticipated money stock, (1) during periods when the Fed was not committed to strict monetary aggregate targets (1977 to 1979 in their analysis), spot prices on primary commodities increased while (2) during periods of monetary aggregate targeting and Fed credibility (1980 to 1982), spot prices on primary commodities fell. Their model provides an adequate explanation for both periods with the spot commodity price overshooting equilibrium.

Figures 2 and 3 show likely paths for prices under the two monetary policy regimes in a steady-growth-state economy with inflation.\(^4\) The announcement of a larger than anticipated money stock is made at time \(t(0)\). In the periods without commitment to monetary aggregate targeting (Figure 2), both the equilibrium price and the (flexible) primary commodity price increase with the flexible price overshooting the equilibrium. With a monotonic adjustment to equilibrium, the deviation is eliminated over a \(j\)-period horizon (with no restriction on the value of \(j\) across or within the cases). During periods of
commitment to monetary aggregate targeting (Figure 3), the announcement of a larger than anticipated money stock triggers a decline in equilibrium prices and the flexible spot commodity price, again, overshoots the equilibrium (on the downside here).

Cornell and French (1986) interpret the response of the commodity basis (the far-near price spread) as a measure of the response of inflation expectations to the money announcement. When nonneutralities are accounted for, it becomes clear that the basis is actually measuring "flex-price inflation" rather than general or equilibrium inflation. For example, Figure 3 shows that flex-price inflation (C to E*) exceeds equilibrium inflation (E' to E*). The absolute magnitudes and the way the figures are drawn are not important; the relative magnitudes are what matter. The relative magnitudes show that, with nonneutralities, the commodity basis cannot be used as an accurate measure of expected (aggregate or equilibrium) inflation. In fact, it would be possible to observe a large positive response in the flex-price commodity basis and yet aggregate inflation over the horizon could be expected to decline. The point to be made is that nonneutralities exist that drive real commodity prices. The far-near commodity price spread would then incorporate the real interest rate in addition to the inflation expectation components of the nominal interest rate.

Some additional evidence is provided by the empirical results of Kitchen and Denbaly (1987) and Fama and French (1987). In this work, the relationships employed are straightforward and they are based on the regression approaches used in Fama (1984a and b) and Fama and French (1987). The regression approach used in those studies is based on adding-up constraints between
dependent variables in several regressions and an identical independent variable in each of the regressions. That is, consider the regressions

\[ \ln F(t, t + j) - \ln S(t) = a + b i(t, t + j) + e(t, t + j) \]

\[ \ln S(t) - \ln F(t, t + j) + i(t, t + j) = c + d i(t, t + j) + w(t, t + j) \]

where \( e(t, t + j) \) and \( w(t, t + j) \) are regression errors and \( a, b, c, \) and \( d \) are regression coefficients. As discussed in detail in Fama (1984a and b), the following constraints hold for the estimated coefficients:

\[ a + c = 0 \]

\[ b + d = 1.0. \]

It is also true that the standard errors of these coefficient estimates are identical across equations—that is, \( s(a) = s(c) \) and \( s(b) = s(d) \). These constraints must hold since the left-hand side (LHS) variables in (6) and (7) sum to the right-hand side variable used in each regression. Kitchen and Denbaly (1987) and Fama and French (1987) presented empirical results for regression (6). Since the LHS variable in (7) is simply the commodity own rate as examined in Cornell and French (1986), evidence on the relation between commodity own rates and the nominal interest rate is implicitly obtained in the regression estimates of Kitchen and Denbaly (1987) and Fama and French (1987) through the relations in (8) and (9). That is, the \( c \) and \( d \) coefficients of (7) can be derived from the \( a \) and \( b \) coefficient estimates of those studies. The derived \( c \) coefficients reveal that significant nonstochastic own rates of interest (convenience yields) exist for the agricultural commodities. No significance of the \( c \) coefficients is observed for the metals. Contrary to the
results observed by Cornell and French (1986) and the relationship between the convenience yield and the nominal interest rate hypothesized by Gordon (forthcoming), the d coefficient estimates reveal no significant relation between commodity own rates and the nominal interest rate—that is, d is not significantly different from zero (see Table 1). However, this result is subject to the qualification that it applies to the entire sample periods of the studies: 1971 to 1986 for Kitchen and Denbaly (1975 to 1986 for gold) and, for Fama and French, various sample periods across commodities covering the years 1966 to 1984. Shorter sample periods covering different policy regimes could potentially produce different results. This possibility reveals an interesting topic for further research.

To make this possibility and the above discussion a little clearer, consider the slope coefficients in (6) and (7) which, by definition, are

\[
\begin{align*}
(10) & \quad b = \frac{\text{Cov}(F - S, i)}{\text{Var}(i)} \\
(11) & \quad d = \frac{\text{Cov}(S - F + i, i)}{\text{Var}(i)} = \frac{-\text{Cov}(F - S, i) + \text{Var}(i)}{\text{Var}(i)}
\end{align*}
\]

(where the time notation has been dropped for notational simplicity). Consider also the case of nonneutralities so that the real interest rate deviates from its steady-growth-state value (also often called a long-run equilibrium value):

\[
(12) \quad i = \bar{r} + z + \pi
\]

where \(\bar{r}\) is the steady-growth-state value of the real interest rate deviation \(z = r - \bar{r}\), and \(\pi\) is the inflation expectation. Then

\[
(13) \quad \text{Cov}(F - S, i) = \text{Cov}(F - S, \bar{r}) + \text{Cov}(F - S, z) + \text{Cov}(F - S, \pi)
\]
TABLE 1

Implied Coefficient Estimates for Own Rate Regression:
\[ \ln S(t) - \ln F(t, t + j) + i(t, j) = c + d i(t, j) + w(t, j) \]

<table>
<thead>
<tr>
<th>Commodity</th>
<th>c</th>
<th>s(c)</th>
<th>d</th>
<th>s(d)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metals</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gold</td>
<td>-0.88</td>
<td>1.08</td>
<td>0.13</td>
<td>0.24</td>
</tr>
<tr>
<td>Silver</td>
<td>1.34</td>
<td>1.84</td>
<td>-0.29</td>
<td>0.41</td>
</tr>
<tr>
<td>Grains</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Corn</td>
<td>4.03</td>
<td>2.60</td>
<td>0.42</td>
<td>0.61</td>
</tr>
<tr>
<td>Oats</td>
<td>9.08</td>
<td>4.68</td>
<td>-0.00</td>
<td>1.09</td>
</tr>
<tr>
<td>Soybeans</td>
<td>8.57</td>
<td>3.29</td>
<td>-0.91</td>
<td>0.71</td>
</tr>
<tr>
<td>Wheat</td>
<td>8.81</td>
<td>4.24</td>
<td>-0.70</td>
<td>0.99</td>
</tr>
<tr>
<td>Stacked grains</td>
<td>7.62</td>
<td>1.91</td>
<td>-0.30</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Note: Derived from results presented in Kitchen and Denbaly (19_). Similar results for the d coefficient can be obtained from the results presented in Fama and French (1987). The results for the intercept and seasonal dummy variables were not reported there so the c coefficients cannot be derived.
\[ \text{Var}(i) = \text{Var}(\tilde{r}) + \text{Var}(z) + \text{Var}(\pi) + 2[\text{Cov}(\tilde{r}, z) + \text{Cov}(\tilde{r}, \pi) + \text{Cov}(z, \pi)]. \] 

Therefore, observing on average over time that \( b = 1.0 \) and \( d = 0 \) is equivalent to simply having the \( \text{Cov}(F - S, \tilde{r}) \) and the summation \( \text{Var}(\tilde{r}) + 2[\text{Cov}(\tilde{r}, z) + \text{Cov}(\tilde{r}, \pi)] \) both being small relative to \( \text{Var}(i) \). That is, \( F - S \) may be sensitive to real interest rate changes associated with nonneutralities but could be unrelated to changes in the steady-growth-state real rate. Provided that \( \tilde{r} \) is relatively stable, regression estimates would tend to show that the far-near commodity price spread exactly incorporates the nominal interest rate even if the Cornell and French (1986) story (adjusted for nonneutralities) is correct. With this interpretation, the combined empirical results from Kitchen and Denbaly (19__), Fama and French (1987), and Cornell and French (1986) would suggest that steady-growth-state real interest rate was generally stable over the 1966-1986 period but that there may have been money related increases in the rate over the 1980 to 1982 period.\(^5\)

Of course, several alternatives to this interpretation exist. For example, there may have been a shift in the relation between the short-run real interest rate deviation, \( d \), and the nonneutral response of commodity prices. Or, it may simply be the case that futures prices are biased predictors of subsequent spot prices and that the risk premium is nonzero on average and related to the real interest rate.

IV. SUMMARY AND CONCLUSIONS

There are subtle differences in the view in the literature about the relationship between interest rates and commodity prices. Cornell and French (1986) argue that commodity own rates and real interest rates are directly
related and that only the inflation expectation (and inflation risk, if any) components of the nominal interest rates are reflected in far-near commodity price spreads. Under alternative views (the theory of storage and the Frankel arbitrage approaches), full nominal interest costs are completely incorporated in contracted returns on commodities.

The existence of arbitrage costs leads to problems in the interpretation of the Cornell and French (1986) empirical results, and it is possible to interpret the results as being consistent with the alternative view of the strict arbitrage and theory of storage approaches. The interpretation is also complicated by the existence of nonneutralities. With nonneutral impacts, the expected rate of change of primary commodity prices can differ from the expected aggregate or equilibrium inflation, and substitution effects can lead to changing expenditure patterns. As a result, and contrary to the Cornell and French (1986) interpretation, the change in the primary commodity basis would be a poor measure of the change in (aggregate or equilibrium) inflation expectations, and a change in primary commodity own rates would not necessarily signal a change in the real interest rate in the economy.

Most of the evidence in the literature supports the theory of storage and arbitrage approach. However, this evidence is from a broad time horizon covering vastly different policy regimes and the associated interest rate and inflation relationships. So, while there are potential problems with the interpretation of the Cornell and French (1986) empirical results, it is possible that their observed relationship between commodity own rates and nominal interest rates is correct for periods when real interest rates are inordinately high. Providing further information on these relationships between real interest rates, commodity prices, and implied commodity price dynamics is an interesting area for further research.
FOOTNOTES

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1In contrast, Working (1949) has stated, "It is only supplies already in existence which have any significant bearing on ... current intertemporal price relationships...." Only a static theory would support such a statement.

2Frankel (1984, p. 565) downplayed the importance of the risk premium: "With conventional estimates of the coefficient of risk aversion and the variances of asset prices, the [Capital Asset Pricing] model suggests that the risk premium cannot be much more than a few basis points."

3The reader is directed to Fama and French (1987) for further details. See also Duzak (1973), Hazuka (1984), Carter, Rausser, and Schmitz (1983). The simple interpretation that \( p(t, j) < 0 \) is for the case in which all hedgers are physically long the underlying commodity. If all hedgers or potential hedgers were users of the commodity, then the existence of a risk premium would suggest that future prices would be an upward biased predictor of subsequent spot prices.

4These price and inflation responses are based on the theory and observed empirical results in the literature, particularly Frankel and Hardouvelis (1985) and Kitchen and Denbaly (1987). The responses shown are not inconsistent with the empirical results of Cornell and French (1986). The theoretical presentation in Cornell and French (1986) does not suggest such responses since they assume away nonneutralities.
For a neoclassical approach as in the Cornell and French (1986) theory, in (12 to 14) and the accompanying discussion, the $z$ term would represent a risk premium associated with inflation uncertainty and the steady-growth-state real rate would be replaced with the ex ante real interest rate. Similar conclusions would emerge. Another point to be made is that the empirical results of Cornell and French (1986) were most likely dominated by the relations for precious metals due to the adjustment for heteroskedasticity used in the regression analysis.
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