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Mean Reversion in Equilibrium Asset Prices: Evidence from the Futures Term Structure

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ABSTRACT

We use the term structure of futures prices to test whether investors anticipate mean reversion in spot asset prices. The empirical results indicate mean reversion in each market we examine. For agricultural commodities and crude oil the magnitude of the estimated mean reversion is large; for example, point estimates indicate that 44 percent of a typical spot oil price shock is expected to be reversed over the subsequent eight months. For metals, the degree of mean reversion is substantially less, but still statistically significant. We detect only weak evidence of mean reversion in financial asset prices.

IN THIS STUDY, WE provide evidence of mean reversion in the prices of several real and financial assets. Rather than examining evidence of ex post reversion using time series of asset prices, we use price data from futures contracts with varying delivery horizons to test whether investors *expect* asset prices to revert. This approach offers two advantages. First, since futures prices are readily available for many markets, our procedure can be implemented for many assets, including those for which reliable spot price data is elusive. Second, there is little ambiguity as to the source of any mean reversion detected using our method. Subject only to the maintained assumption that the no-arbitrage cost-of-carry condition holds, our test detects mean reversion that is expected to occur in equilibrium, but has no power to detect mean reversion resulting from noise or inefficiencies.

Our methodology focuses on relations between price levels and the slope of the futures term structure, defined as the change across delivery dates in the futures prices observed on a given trading date. An inverse relation between prices and the futures term slope constitutes evidence that investors expect mean reversion in spot prices. To illustrate, initially assume there are no

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futures risk premia, so that each futures price equals the trading date expectation of the delivery date spot price. The term structure of futures prices then describes several points on the path that investors expect the spot price will take. Detecting an inverse relation between price levels and the term slope then implies a lower rate of expected intertemporal price appreciation when prices rise, and vice versa. This is indicative of mean reversion.

This approach has power to detect mean reversion, because a subset of the causes of mean reversion also affects the slope of the equilibrium futures term structure. The cost-of-carry or storage model of futures prices describes the futures term structure based on a no-arbitrage condition: the slope of the futures term structure equals the net cost of holding the asset in inventory between delivery dates. This net cost is comprised of the interest rate less the rate of benefit (dividend, coupon payment, or service flow net of storage costs) accruing to the marginal holder of the asset. We refer to this benefit as the implied cash flow yield.

Given the cost-of-carry condition, our approach can detect equilibrium mean reversion from two sources. One source is positive comovement between prices and implied cash flow yields. If prices are mean reverting, then price changes contain a temporary component, and subsequent capital gains or losses are partially predictable. If prices and cash flow yields covary positively, however, then the expected excess capital gains or losses implied by mean reversion are offset by changes in implied cash flow yields, allowing the asset to continue offering a competitive expected return. The second source of equilibrium mean reversion is negative correlation between interest rates and prices. For a given set of implied cash flows, mean reversion will be observed if interest rate changes cause opposite direction changes in spot prices.

Fama and French (1988a) argue that negative comovement between prices and risk premia can generate mean reversion in equilibrium. Poterba and Summers (1988) focus on the possibility that mean reversion results from temporary divergences of prices from fundamental value. This possibility can also be represented as negative comovement between (disequilibrium) premia and prices. Our tests can detect mean reversion resulting from movement in the interest rate component of expected returns, but not from movement in the risk premium component.

We conduct our empirical analysis using data from eleven disparate futures markets, including financials, metals, and agriculturals, and find some evidence of mean reversion in every market. For agricultural commodities and crude oil, mean reversion arises solely from positive comovement between prices and implied cash flow yields. In these markets, the magnitude of the estimated mean reversion is large. For example, point estimates indicate that 44 percent of a typical spot oil price shock is expected to be reversed over the subsequent eight months. For metals, mean reversion arises both from interest rate sensitivity and from positive comovement between prices and implied cash flow yields, but the degree of mean reversion is small relative to oil and agricultural markets. Finally, for financial assets, the evidence of mean reversion is weak and, as might be expected, is attributable entirely to interest rate sensitivity.

Finding significant mean reversion in real asset prices has important practical implications. For example, the return forecastability associated with mean reversion in asset prices implies that return variances do not increase linearly with the measurement interval, as they would if prices followed a random walk. Lo and Wang (1994) show that option prices depend on the degree and type of return forecastability, because of interactions between forecastability and risk. This implies that the equilibrium prices of many derivatives based on real asset prices are affected by mean reversion. Similarly, Laughton and Jacoby (1993) show that failure to accommodate mean reversion in macroeconomic factors (e.g., oil prices) can lead to overestimation of risk and systematic biases in capital budgeting decisions.

Our analysis is organized as follows. In Section I we extend the cost-of-carry model to demonstrate how examining the futures term structure can provide evidence regarding mean reversion in spot prices. In Section II we describe our data and statistical methods. Section III describes our empirical findings, while Section IV provides a brief conclusion.

I. Background and Hypothesis Development

A. The Cost-of-Carry Model

Let $F_t(m)$ denote the date t futures price for delivery at date $t + m$, and P_t denotes the date t spot price. The cost-of-carry relation, which dates to Working (1949) and Brennan (1958), can be stated as:

$$F_t(m) = P_t \cdot e^{(r_t - c_t)m} \tag{1}$$

where r_t is the continuously compounded per period interest rate, and c_t is the implied cash flow yield (dividend, coupon, or service flow net of storage costs) to the marginal owner of the asset, stated as a percentage of the asset price on a continuously compounded per period basis. Note that $r_t - c_t = s_t$ is the slope of the futures term structure. In the absence of transactions costs, and abstracting from the daily settlement and delivery option features of futures contracts, equation (1) describes a no-arbitrage condition. In equilibrium, the marginal holder of inventory is indifferent between earning c_t from holding the asset or by "lending" (by selling at the spot, investing the proceeds at r_t, and buying at the future) it to risklessly earn the same amount in cash. We take the validity of the cost-of-carry relation (1) as a maintained hypothesis.

B. Mean Reversion and the Futures Term Structure

Define π_t as the per-period bias in the period t futures price as a forecast of the future spot price:

$$\pi_t = \frac{\ln[E_t(P_{t+m})/F_t(m)]}{m} \tag{2}$$

In equilibrium, π_t is the expected risk premium earned by speculators who hold a long futures position. Using equations (1) and (2), we can express the current spot price as

$$P_t = \frac{E_t(P_{t+m})}{e^{m(r_t + \pi_t - c_t)}} \tag{3}$$

We assume that the implied cash flow yield, the risk premium, and the interest rate can each be stated as differentiable functions of the spot asset price: $c_t = c(P_t)$, $\pi_t = \pi(P_t)$, and $r_t = r(P_t)$, with first derivatives c', π', and r', respectively.[1] We define mean reversion as a percentage change in the date t expectation of the date $t + m$ spot price that is less than the percentage change in the date t spot price. An elasticity less than unity implies mean reversion since a component of the spot price shock is temporary, and is expected to be reversed by date $t + m$. Using equation (3), the elasticity of the date t expectation of the date $t + m$ spot price with respect to the date t spot price is:

$$\varepsilon_{E(P),P} \equiv \frac{\partial E_t(P_{t+m})}{\partial P_t} \cdot \frac{P_t}{E_t(P_{t+m})} = 1 + m \cdot P_t[r' + \pi' - c']. \tag{4}$$

Equation (4) implies that mean reversion occurs if and only if $[r' + \pi' - c'] < 0$.

We cannot observe π_t or $E_t(P_{t+m})$. However, from equation (4) we see that if π' is not positive, then a finding of $(r' - c') < 0$ is a sufficient condition for inferring that $\varepsilon_{E(P),P} < 1$, and it constitutes evidence that investors expect spot prices to revert. Time-varying risk premia are widely viewed (e.g., Fama and French (1988a)) as a potential source of mean reversion, implying that π' is negative. Also, mean reversion resulting from inefficiencies can be represented as negative comovement between prices and (disequilibrium) premia. Finally, from equation (3), π_t is a component of the discount rate. General valuation theories imply that value can be stated as the discounted worth of future benefits to holding the asset and, ceteris paribus, value falls with discount rates. Hence, we make the maintained assumption that π' is not positive.[2]

[1] It may be more natural to think of causation running in the opposite direction, with interest rates and risk premia affecting asset prices. However, since we are concerned only with the sign of the relation, the direction of causation is immaterial to our analysis.

[2] In earlier versions of this article we also provided empirical evidence regarding the validity of this assumption by regressing estimates of risk premia on the near futures price. Since the futures risk premia is the expected rate of change in a given contract's delivery price, the actual rate of change in the delivery price is the premia plus a forecast error. Thus, we estimate π' by regressing observed ex post changes in futures prices on the level of the near price on the prior day. For virtually all markets and maturities in our sample, the resulting π' estimates are negative, although none are statistically significant. These results, which are available from the authors, indicate that variation in risk premia do not overturn our findings of mean reversion in spot asset prices. Rather, these results comprise weak evidence that comovement between prices and risk premia constitutes an additional source of mean reversion that is not detected by our reported tests.

The elasticity of the future price $F_t(m)$ with respect to the contemporaneous spot price is observable and, based on the cost-of-carry equilibrium (1), can be expressed as:

$$\varepsilon_{FP} \equiv \frac{\partial F_t(m)}{\partial P_t} \cdot \frac{P_t}{F_t(m)} = 1 + m \cdot P_t[r' - c']. \tag{5}$$

The cost-of-carry equilibrium predicts that this elasticity will be less than one, implying mean reversion in spot prices, if $s' = r' - c' < 0$, that is, if the slope of the futures term structure declines when prices rise, and vice versa. Intuitively, there are two cases where mean reversion can occur in equilibrium. The first is when implied cash flow yields covary positively with spot prices ($c' > 0$, $r' = 0$) so that changes in cash flow yields compensate for the unusual capital gain or loss implied by the reversion of prices. An example would be a temporary increase in a stock's dividend payout, which would increase the stock price prior to the payout date, but not the expected postpayout spot price. The second occurs when interest rates covary negatively with spot prices ($r' < 0$, $c' = 0$), so that spot prices shift in reaction to changes in the interest rate component of expected returns. An example would be an increase in real interest rates that raise discount rates without proportionate increases in expected future cash flows. This would result in an asset price decline, followed by higher mean returns.

Empirically, we examine mean reversion two ways. First, we estimate the derivatives s', r', and c' directly. Second, we estimate the elasticity of distant futures prices with respect to spot prices. Equation (4) implies that, if mean reversion occurs, the futures-spot elasticities should be less than one, and should decline with maturity. If the cost-of-carry equilibrium holds, both estimation procedures should provide consistent results.

II. Data and Methods

A. Choice of Contracts

We use daily settlement prices for eleven futures markets over the interval January 1982 to December 1991, obtained from Data Resources, Inc. (DRI).[3] There are problems inherent in the use of spot price data for several of the asset markets we examine. These include nonsynchronous observation of spot and futures prices and high rates of data errors in the available computerized databases. Accordingly, we follow Fama and French (1987) and Bailey and Chan (1993) in using the nearest to maturity futures price as a proxy for the spot price.

We select eleven futures markets to provide cross-sectional variation in potential sources of mean reversion. We use five agricultural commodities, including Wheat, Live Cattle, Orange Juice, World Sugar, and Domestic Sugar, anticipating that convenience yields (service flows) are important for

[3] Three of the futures contracts in our sample commenced trading subsequent to January 1982: the S&P 500 (April 1982), Crude Oil (March 1983), and Domestic Sugar (September 1985).

agricultural markets.[4] Results for World (unregulated) and Domestic (regulated) Sugar can be contrasted to examine the effects of regulation: with the exception of a small quota dictated by the U.S. government, world sugar cannot be imported for delivery on the domestic sugar contract. We also include four mineral contracts: Crude Oil, Gold, Silver, and Platinum.[5] Like agricultural futures, we anticipate that convenience yields will be important for the metals contracts, but smaller and less variable. Finally, we include two financial contracts, the S&P 500 Index and Treasury bonds, for which no storage costs or convenience yield is likely to be included in the implied cash flow yield.

B. Measurement of Cash Flow Yields

We use data on the observed term structure of futures prices to obtain estimates of implied cash flow yields to holders of the spot asset. To do so, we must incorporate the foregone interest component of carrying costs. Let $r_{m,t}$ denote the per-period, continuously compounded, spot interest rate applicable to the interval from t to $t + m$. Forward interest rates for the interval from time $t + n$ to time $t + m$ are then defined as:

$$r_{nm,t} = r_{m,t}\left(\frac{m}{m-n}\right) - r_{n,t}\left(\frac{n}{m-n}\right). \tag{6}$$

We estimate forward interest rates by applying equation (6) to Treasury Bill yields obtained from DRI.

Applying equation (1) to futures with maturity dates of $t + n$ and $t + m$, we can obtain implied forward cash flow yields from pairs of futures prices according to:

$$c_{nm,t} = r_{nm,t} - \frac{\ln(F_t(m)/F_t(n))}{(m-n)} \tag{7}$$

C. Methodological Issues

We analyze the behavior of futures prices separately on the basis of a variable we term "nearby," which indicates relative nearness to expiration; Nearby = 1 denotes the contract nearest to expiration (except that we do not

[4] The theoretical analysis of French (1986) and the empirical study of Fama and French (1987) indicate that variation in marginal convenience yields (service flows) is important in determining the markets in which spot price changes will be forecastable. Although they do not specifically address mean reversion, Fama and French (1987) find that instrumental variables contain power to forecast changes in spot prices primarily in markets for agricultural and animal products, where convenience yields are likely to be variable. Fama and French (1988b) extend the analysis to show that the relative volatility of spot and futures prices depends on marginal convenience yields. Consistent with their reasoning, they show that spot metals prices are more volatile than futures when bases are unusually high, and vice versa.

[5] Metals markets trade contracts for both "major" and "minor" months. Major contracts commence trading a year or more prior to maturity, while minor months commence trading two or three months prior to maturity. We confine our analysis to major contracts, which are characterized by substantially larger volumes and open interest.

use prices within the delivery month), Nearby = 2 is the second nearest, etc. To mitigate possible bias due to light trading we exclude from our tests any nearbys if data is not available for at least 80 percent of all trading dates. All of our results are quite uniform across nearbys, and our conclusions would be unaffected if the analysis were further limited to nearer and more liquid maturities.

Statistical inference in this dataset is not straightforward due to two sources of dependence among the observations. First, observations on a given trading date for different delivery dates are highly correlated. Second, observations on the future term slope and implied cash flow yields for each contract are autocorrelated over time. Throughout this study, we accommodate these sources of dependence as well as generalized forms of heteroskedasticity by employing Newey-West (1987) standard errors.[6]

III. Empirical Results

A. *Determinants of Mean Reversion: Prices and the Slope of the Futures Term Structure*

In Section II we derived that, if the cost-of-carry relation (1) holds, then mean reversion occurs if $s' = r' - c'$ is negative. That is, if increases in the spot price are accompanied by decreases in the slope of the futures term structure, and vice versa, mean reversion in spot prices is implied. We evaluate the occurrence of mean reversion separately by nearby using the variable:

$$s_{nm,t} \equiv \frac{\ln(F_t(m)/F_t(n))}{(m-n)} = r_{nm,t} - c_{nm,t}, \tag{8}$$

which is the slope of the date t futures term structure over delivery dates $t + n$ to $t + m$.

In Tables I, II, and III we report results of regressions that estimate the derivatives with respect to price s', c', and r', respectively. Since the dependent variable in the first specification is the difference between the dependent variables in the next two, the same relation exists between estimated slope coefficients. For reasons outlined earlier, we use the near futures price as a proxy for the spot price. Due to the high autocorrelation and potential nonstationarity in the term slope and its components, we estimate these regressions using first differences of each data series. To facilitate comparison of coefficient estimates, each price series is scaled by dividing by its own mean.

[6] To conduct tests involving K nearbys we employ $K + 1$ lags to compute the Newey-West covariance matrix. With the data sorted by trading date and then by delivery date, a lag $K + 1$ adjustment accommodates the dependence across the K contracts as well as first-order autocorrelation across observation dates. Joint hypotheses are tested using the Wald statistic $W = (\mathbf{RB})'(\mathbf{RNR})^{-1}(\mathbf{RB})$ where $\mathbf{R}$ is the restriction matrix of rank q, $\mathbf{B}$ is the coefficient matrix, and $\mathbf{N}$ is the Newey-West matrix. The Wald statistic follows an asymptotic chi-square distribution with q degrees of freedom.

Table I

Relations between the Slope of the Futures Term Structure and the Level of Prices

These are estimated slope coefficients from regressing the futures term slope: $s_{nm,t} = \ln(F_t(m)/F_t(n))/(m - n)$, where $F_t(k)$ is the date t futures price for delivery at date $t + k$, on the near futures price, which we use as a proxy for the spot. Coefficients are estimated separately by nearness to contract expiration. Nearby 2 denotes results obtained using prices for the nearest and second nearest delivery dates; Nearby 3 denotes results obtained using prices for the second and third nearest delivery dates, etc. Regressions are estimated in first differences. Standard errors are in parentheses. To facilitate comparisons of coefficient estimates each price has been divided by its own time series mean. Each dependent variable has been multiplied by 25,000 and can be interpreted as an annualized percentage.

Nearby	Crude Oil[a]	Silver[b]	Gold[b]	Platinum[c]	Wheat[d]	Orange Juice[c]	Domestic Sugar[c]	World Sugar[f]	Cattle[b]	Treasury Bonds[g]	All Data S&P 500[g]	Excluding Crash S&P 500[gh]
2	−148.76	−5.24	−0.70	−3.82	−35.92	−96.74	−194.92	−37.36	−38.96	0.28	−0.19	1.78
	(11.82)	(1.63)	(0.39)	(0.42)	(4.55)	(7.56)	(11.72)	(3.63)	(4.05)	(0.60)	0.82)	(0.81)
3	−50.08	−4.14	−1.46	−3.57	−27.14	−22.15	−47.97	−36.16	−53.44	−1.05	−1.75	0.29
	(5.17)	(1.22)	(0.32)	(0.46)	(5.12)	(4.95)	(8.56)	(3.40)	(2.94)	(0.64)	(0.48)	(0.47)
4	−29.72	−2.82	−1.59	−3.41	−18.95	−12.31	−17.67	−14.87	−29.23	−0.67	−1.89	−1.83
	(3.24)	(1.48)	(0.44)	(0.40)	(2.88)	(2.60)	(9.40)	(3.54)	(2.76)	(0.62)	(1.63)	(1.62)
5	−21.81	−5.32	−1.78	−3.48	−19.39	−12.31	−15.21	−10.42	−16.81	−0.77		
	(3.52)	(1.12)	(0.37)	(0.70)	(3.19)	(3.31)	(10.09)	(3.34)	(2.19)	(0.64)		
6	−18.41	−3.58	−1.65			−5.98	−27.59		−25.73	−0.96		
	(3.71)	(1.17)	(0.38)			(2.39)	(1.323)		(3.55)	(0.64)		
7	−16.44	−3.24	−1.86			−9.25				−1.03		
	(4.00)	(1.73)	(0.36)			(2.92)				(0.67)		
8	−16.32		−0.59							−0.49		
	(2.79)		(0.33)							(0.46)		
Test: all zero χ^2(p-value)	256.42	55.96	41.59	110.19	119.97	200.14	432.14	215.34	449.31	6.73	16.24	4.64
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.457)	(0.001)	(0.200)

[a] Delivery months are 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, and 12.
[b] Delivery months are 2, 4, 6, 8, 10, and 12.
[c] Delivery months are 1, 4, 7, and 10.
[d] Delivery months are 3, 5, 7, 9, and 12.
[e] Delivery months are 1, 3, 5, 7, 9, and 11.
[f] Delivery months are 3, 5, 7, and 10.
[g] Delivery months are 3, 6, 9, and 12.
[h] Excludes data from October 15 to 31, 1987.

Table II

Relations between Implied Cash Flow Yields and the Level of Prices

This table reports estimated slope coefficients from regressing implied cash flow yields: $c_{nm,t} = r_{nm,t} - [\ln(F_t(m)/F_t(n))/(m-n)]$, where $F_t(k)$ is the date t futures price for delivery at date $t+k$ and $r_{nm,t}$ is the date t forward interest rate applicable to the interval $t+n$ to $t+m$, on the near futures price, which we use as a proxy for the spot. Coefficients are estimated separately by nearness to contract expiration. Nearby 2 denotes results obtained using prices for the nearest and second nearest delivery dates; Nearby 3 denotes results obtained using prices for the second and third nearest delivery dates, etc. Regressions are estimated in first differences. Standard errors are in parentheses. To facilitate comparison of coefficient estimates, each price has been divided by its own time series mean. Each dependent variable has been multiplied by 25,000 and can be interpreted as an annualized percentage.

Nearby	Crude Oil	Silver	Gold	Platinum	Wheat	Orange Juice	Domestic Sugar	World Sugar	Cattle Cattle	Treasury Bonds	All Data S&P 500	Excluding Crash S&P 500[a]
2	148.75	4.87	0.11	3.64	35.89	96.54	195.19	37.49	38.93	−4.63	−0.17	−1.98
	(11.83)	(1.65)	(0.41)	(0.42)	(4.56)	(7.56)	(11.07)	(3.61)	(4.05)	(0.56)	(0.91)	(0.89)
3	50.24	3.95	0.94	3.35	27.17	22.46	48.42	36.22	53.35	−3.94	1.32	−0.76
	(5.13)	(1.23)	(0.24)	(0.43)	(5.11)	(4.89)	(8.41)	(3.41)	2.43)	(0.43)	(0.64)	(0.62)
4	29.69	2.66	1.20	3.19	19.03	12.34	17.48	14.91	29.01	−5.29	1.71	1.41
	(3.23)	(1.51)	(0.34)	(0.41)	(2.90)	(2.74)	(9.58)	(3.55)	(2.74)	(0.40)	(1.38)	(1.39)
5	21.78	5.13	1.24	3.36	19.60	12.36	15.11	10.55	16.63	−4.94		
	(3.51)	(1.14)	(0.31)	(0.66)	(3.19)	(3.28)	(10.14)	(3.33)	(2.17)	(0.36)		
6	18.39	3.42	1.19			6.05	27.75		25.50	−4.08		
	(3.75)	(1.18)	(0.30)			(2.36)	(12.91)		(3.56)	(0.31)		
7	16.48	3.94	1.19			9.55				−4.03		
	(3.88)	(1.74)	(0.28)			(2.99)				(0.32)		
8	16.45	1.44								−4.82		
	(2.75)	(0.25)								(0.40)		
Test: all zero	258.64	49.58	56.25	108.95	119.52	198.76	463.15	217.51	454.71	496.31	7.25	4.68
χ^2(p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.064)	(0.196)

[a] Excludes data from October 15 to 31, 1987.

Table III

Relations between Forward Interest Rates and the Level of Prices

This table reports estimated slope coefficients from regressing forward interest rates, $r_{nm,t}$ on the near futures price, which we use as a proxy for the spot. Coefficients are estimated separately by nearness to contract expiration. Nearby 2 denotes results obtained using prices for the nearest and second nearest delivery dates; Nearby 3 denotes results obtained using prices for the second and third nearest delivery dates, etc. Regressions are estimated in first differences. Standard errors are in parentheses. To facilitate comparison of coefficient estimates each price has been divided by its own time series mean. Each dependent variable has been multiplied by 25,000 and can be interpreted as an annualized percentage.

Nearby	Crude Oil	Silver	Gold	Platinum	Wheat	Orange Juice	Domestic Sugar	World Sugar	Cattle	Treasury Bonds	All Data S&P 500	Excluding Crash S&P 500[a]
2	−0.00	−0.36	−0.59	−0.18	−0.03	−0.19	0.27	0.13	−0.03	−4.35	−0.36	−0.19
	(0.22)	(0.16)	(0.23)	(0.14)	(0.14)	(0.25)	(0.85)	(0.08)	(0.22)	(0.42)	(0.26)	(0.28)
3	0.16	−0.18	−0.52	−0.22	0.03	−0.05	0.45	0.06	−0.08	−4.99	−0.43	−0.47
	(0.29)	(0.14)	(0.24)	(0.14)	(0.11)	(0.19)	(0.89)	(0.06)	(0.15)	(0.47)	(0.31)	(0.32)
4	−0.03	−0.16	−0.39	−0.21	0.08	0.02	−0.19	0.04	0.23	−5.96	−0.18	−0.42
	(0.14)	(0.12)	(0.18)	(0.16)	(0.11)	(0.25)	(0.73)	(0.08)	(0.14)	(0.64)	(0.51)	(0.53)
5	−0.03	−0.19	−0.53	−0.12	0.21	0.05	−0.11	0.12	−0.18	−5.71		
	(0.12)	(0.18)	(0.26)	(0.17)	(0.18)	(0.27)	(0.70)	(0.11)	(0.18)	(0.71)		
6	−0.01	−0.15	−0.46			0.07	0.16		−0.28	−5.04		
	(0.16)	(0.21)	(0.30)			(0.34)	(1.07)		(0.31)	(0.63)		
7	0.04	0.71	−0.67			0.30				−5.05		
	(0.32)	(0.23)	(0.27)			(0.46)				(0.62)		
8	0.12		0.85							−5.32		
	(0.18)		(0.23)							(0.63)		
Test: all zero	1.13	21.01	41.57	3.19	1.87	1.70	0.052	5.83	2.92	166.29	4.57	2.56
χ^2(p-value)	(0.992)	(0.001)	(0.000)	(0.526)	(0.758)	(0.944)	(0.991)	(0.212)	(0.712)	(0.000)	(0.206)	(0.465)

[a] Excludes data from October 15 to 31, 1987.

Table I reports estimates of s' obtained by regressing the change in the futures term slope on the change in the near futures price. For the commodity markets, including metals, crude oil, and agriculturals, the regression coefficients are uniformly negative and significant, implying that increases in the level of commodity prices tend to be accompanied by decreases in the slope of the commodity futures term structure, and vice versa. Although we can detect a significant negative relation for metals, the coefficient estimates are orders of magnitude less than those for the agricultural commodities. We conclude that, for real assets, mean reversion in spot prices is the norm rather than the exception.

For financial assets, the evidence is less clear. Estimates of s' for Treasury bonds are negative for all nearbys, except Nearby = 2, but are not significant. The p-value on a test of the hypothesis that this coefficient is zero for all nearbys is 0.457. We conclude that there is only very weak evidence of mean reversion in Treasury Bond prices. For the S&P 500, use of all data leads to evidence of mean reversion: point estimates of s' are negative, and the hypothesis that each estimate equals zero can be rejected (p-value = 0.001). When we exclude the second half of October 1987, the point estimate of s' is significantly positive for the second nearest S&P contract, which suggests reinforcement rather than reversion. The point estimate for the fourth nearest S&P contract is negative, implying reversion. On balance, evidence for the S&P contract is inconclusive.

Mean reversion can result either from interest rate sensitivity of the spot asset price, or from covariation between spot prices and the rate of cash flow to holders of the asset. Table II reports estimates of c', the sensitivity of implied cash flow yields to prices, obtained by regressing changes in implied cash flow yields on changes in the near futures price. Table III reports estimates of r', obtained by regressing changes in forward interest rates on changes in the near futures price. Positive estimates of c' indicate mean reversion induced by variation in cash flow yields, while negative estimates of r' indicate mean reversion induced by interest rate sensitivity in the asset price.

Fama and French (1988b) predict that price forecastability will be most evident in markets where inventories and hence marginal convenience yields are highly variable, or equivalently, in markets where long-run supply is at times substantially more elastic than short-run supply. Cross-sectional differences in results reported in Table II are consistent with these predictions. Point estimates of c' for Crude Oil and agriculturals are uniformly positive, and the hypothesis that each estimate is zero is rejected for each market. Positive estimates of c' indicate that, when the commodity becomes scarce (as signaled by a price rise), there is a proportionally larger increase in the implied cash flow. This allows for mean reversion in equilibrium, since the increase in cash flow yields offset the forecastable capital loss implied by the reversion of prices. In contrast, point estimates of r' do not differ significantly from zero for these commodities, implying that the forecastability is wholly attributable to shifts in implied cash flow yields. The largest estimates of c' are found in the nearest to delivery contracts for Domestic Sugar (195.19), Crude Oil (148.75), and Orange Juice (96.54). Estimates of this coefficient are similar for the two sugar contracts with the exception of the nearest to delivery, where the coefficient for the domestic contract is roughly five times as large. We interpret this finding as indicating that the constraints imposed by regulation dramatically decrease the elasticity of short run supply, causing large temporary price swings.

Mean reversion in metals markets is attributable to comovement of both interest rates with prices and implied cash flow yields with prices. For each of the three metals markets, all point estimates of c' are positive, while virtually all estimates of r' are negative, and most differ significantly from zero. The significance of the r' estimates for metals is important, as this indicates mean reversion in equilibrium asset prices deriving from shifts in the investment opportunity set.

Estimates of c' for Treasury Bonds are uniformly negative, reflecting that the percentage cash flow yield derived from fixed coupon payments declines with bond prices. Negative estimates of r' reflect the inverse relation between bond prices and interest rates. Estimates of c' smaller in absolute magnitude than corresponding estimates of r' would comprise evidence of mean reversion in bond prices. The actual estimates are roughly equal and hence offsetting.

For the S&P 500, our measure of cash flow yield should capture only dividends. Ceteris paribus, dividend yields fall with stock price increases, implying a negative relation between stock price shocks and measured cash flow yields. However, shifts in dividend payouts can lead to a positive relation between prices and yields, as dividends replace capital gains as a source of expected returns. Empirical results are mixed, with some slopes having a positive estimate. When we exclude the second half of October 1987, the slope coefficients are predominantly negative. We conclude that the slight mean reversion in distant delivery S&P contracts is attributable to interest rate sensitivity, and thus to changes in expected rates of return.

B. Evidence of Mean Reversion Based on Elasticities

In Section III.*A* above we provide evidence of mean reversion based on estimates of the derivative s' and its components, r' and c'. We now provide corroborating evidence by estimating elasticities of futures prices with respect to spot prices. The cost-of-carry-relation implies that if spot prices are mean reverting, then the elasticity of the futures price with respect to the spot price will be less than one and will decline with the time to contract expiration. If the cost-of-carry equilibrium were known to hold at all times, this test for mean reversion would be redundant. However, market imperfections, delivery options, and the daily settlement feature of futures contracts allow for some violations of the cost-of-carry condition. Consistency of results across estimation methods can potentially validate our reliance on the cost-of-carry equilibrium. Also, elasticity point estimates provide readily interpretable estimates of the magnitude of the forecasted mean reversion.

To estimate elasticities of futures prices with respect to spot prices, we regress the first difference of logarithms of distant futures prices on the first difference of logarithms of near futures prices (used as proxies for spot prices).[7] The resulting point estimates are presented in Table IV. Consistent with the existence of mean reversion in spot prices, the estimated elasticities for metals, Crude Oil, and agricultural commodities are uniformly and significantly less than one, and decline monotonically as the time to the futures expiration date increases. Point estimates indicate the greatest degree of mean reversion in agricultural and crude oil markets. For example, for Crude Oil the point estimate on the eighth nearby contract is 0.56, implying that 44 percent of a spot oil price shock is reversed over the subsequent eight months, on average. Estimated elasticities for the fifth nearest Wheat, Orange Juice, World Sugar, and Cattle contracts all lie between 0.50 and 0.67, implying that on average between a half and a third of spot price shocks are expected to be reversed within a year. The coefficients associated with the fourth nearest contracts indicate that roughly one third of all World Sugar price shocks are reversed before expiration of the later contract, while for Domestic Sugar, this proportion is over 70 percent. We again attribute this difference to rigidities in short-run supply caused by regulatory limits on sugar imports. In contrast to results for oil and agriculturals, but consistent with Fama and French (1988b), elasticity estimates for metals are generally above 0.90, indicating a lesser but still significant degree of mean reversion.

Elasticity estimates provide little evidence of mean reversion for financial assets. Point estimates for Treasury bonds are consistent with mean reversion since the elasticities decline monotonically with maturity. However, the decrease is small: the elasticity of the eighth nearest contract, with maturity some two years distant, is 0.969. Also, for Treasury bonds the hypothesis that each elasticity coefficient equals one cannot be rejected (p-value = 0.552). For equities, there is evidence of mean reversion, since estimated elasticities decline with time-to-maturity and the hypothesis that the elasticities equal one another across nearbys can be rejected. However, the decline is again small (the point estimate for the fourth-nearest contract is 0.988), and once again results are driven largely by a few observations in October 1987. When the last two weeks of this month are excluded each estimated elasticity lies between 1.008 and 1.011, and the hypothesis that the elasticities equal each other cannot be rejected.

IV. Conclusions

In this study, we introduce a test for mean reversion in equilibrium asset prices. This test offers two advantages. First, the test can be implemented in

[7] It is readily shown that the elasticity we actually estimate (of the distant future with respect to the near future) is the ratio of two unobservable elasticities: the elasticity we would like to estimate (of the distant future with respect to the spot) to the elasticity of the near future with respect to the spot. If mean reversion occurs, then each unobservable elasticity is less than one, and the net effect of using the near future as a proxy for the spot is to bias our estimates upwards and against detecting mean reversion.

Table IV

Elasticities of Distant Futures Price Changes with Respect to Near Price Changes

This table reports elasticities estimated as slope coefficients in regressions of daily rates of change in distant delivery futures prices, $\ln(F_t(m)/F_{t-1}(m))$, where $F_t(m)$ is the date t futures price for delivery at date $t+m$, on the contemporaneous rate of change in the near (Nearby = 1) delivery futures price. Elasticities are estimated separately by nearness to contract expiration. Estimates less than unity imply mean reversion in asset prices. Standard errors are in parentheses.

Nearby	Crude Oil	Silver	Gold	Platinum	Wheat	Orange Juice	Domestic Sugar	World Sugar	Cattle	Treasury Bonds	All Data S&P 500	Excluding Crash S&P 500[a]
2	0.808	0.985	0.998	0.985	0.874	0.743	0.456	0.831	0.858	1.000	1.001	1.010
	(0.016)	(0.004)	(0.001)	(0.002)	(0.015)	(0.022)	(0.032)	(0.016)	(0.011)	(0.002)	(0.002)	(0.002)
3	0.742	0.972	0.994	0.971	0.783	0.681	0.334	0.712	0.677	0.994	0.995	1.011
	(0.020)	(0.004)	(0.002)	(0.002)	(0.021)	(0.028)	(0.035)	(0.013)	(0.016)	(0.005)	(0.003)	(0.003)
4	0.701	0.964	0.990	0.958	0.720	0.647	0.289	0.650	0.573	0.990	0.988	1.008
	(0.022)	(0.04)	(0.003)	(0.003)	(0.022)	(0.028)	(0.033)	(0.011)	(0.018)	(0.007)	(0.004)	(0.004)
5	0.669	0.948	0.985	0.942	0.662	0.606	0.254	0.600	0.514	0.986		
	(0.023)	(0.005)	(0.004)	(0.004)	(0.022)	(0.028)	(0.038)	(0.010)	(0.018)	(0.010)		
6	0.632	0.938	0.981			0.597	0.139		0.459	0.981		
	(0.025)	(0.006)	(0.004)			(0.028)	(0.044)		(0.019)	(0.011)		
7	0.617	0.888	0.976			0.576				0.976		
	(0.024)	(0.010)	(0.005)			(0.031)				(0.013)		
8	0.564		0.943							0.969		
	(0.028)		(0.009)							(0.016)		
Test: all equal one	439.3	232.5	46.70	275.0	419.0	596.7	1573.0	2421.2	1166.8	5.89	12.16	22.46
χ^2 (p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.552)	(0.007)	(0.000)
Test: all equal	99.42	131.8	44.58	132.0	88.20	3.522	41.71	178.3	483.5	5.76	12.15	0.58
χ^2 (p-value)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.451)	(0.002)	(0.748)

[a] Excludes data from October 15 to 31, 1987.

a broad array of markets, including those where reliable spot price data is lacking. Second, the test allows little ambiguity as to the source of the mean reversion: subject to the maintained assumption that the no-arbitrage cost-of-carry condition holds, our test only detects mean reversion that is expected to occur in equilibrium.

Our approach has power to detect mean reversion, because some of its causes also affect the slope of the equilibrium futures term structure. One possible source of equilibrium mean reversion is positive correlation between assets' implied cash flow yields and prices. A second source of equilibrium mean reversion is negative correlation between interest rates and prices. Mean reversion from either of these sources implies an observable negative relation between spot prices and the slope of the futures term structure.

We conduct our analysis using data from financial, metal, and agricultural markets. For agricultural commodities and Crude Oil, the observed mean reversion is large in magnitude and arises solely from positive comovement between prices and implied cash flow yields. For metals, mean reversion arises from both sources, but the degree of mean reversion is small relative to oil and agricultural markets. For financial assets the evidence of mean reversion is weak.

This empirical evidence is important for at least two reasons. First, documentation of mean-reverting prices in real asset markets has practical implications. For instance, failure to accommodate mean reversion when it exists can lead to systematic biases in capital budgeting decisions and in pricing derivatives. Second, our results confirm that mean reversion in asset prices occurs as an equilibrium phenomenon in some asset markets.

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