1988

"Problems with an Econometric Test of Forecast Accuracy"

by

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Paper presented at the annual meetings of the American Agricultural Economics Association in Knoxville, Tennessee, July 31 - August 3 1988.

Forecasting -- Mathematical models

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Washington DC

#1579

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ABSTRACT

Many economists have used econometric forecast accuracy tests to evaluate the pricing performance of futures markets. Several studies appear to reject the null hypothesis of unbiased forecasts. We show that forecast bias can be a result of misspecification of the model. Alternative tests of market efficiency are discussed.

"Problems with an Econometric Test of Forecast Accuracy"

Introduction

Tests of the accuracy of futures prices as forecasts of subsequent (maturity month) cash or futures prices have become a common feature of agricultural market efficiency studies. Agricultural economists appear to have a general interest in the forecasting ability of futures prices. In a recent survey published in the AJAE Pope and Hallam asked a sample of agricultural economists about the predictive ability of futures prices. Nearly 40 percent of those surveyed agreed that futures prices were poor predictors of future cash price, while almost 50 percent disagreed. 1/ It is likely that many of those agreeing and those disagreeing with the questionnaire's statement considered the results of several widely cited forecast accuracy studies in forming their opinions.

Many economists have used econometric forecast accuracy tests to evaluate the pricing performance of the futures markets. The use of tests of the forecasting power of agricultural futures market prices is commonly traced to the articles by Tomek and Gray, Kofi, and Leuthold. Surprisingly, several of these studies appear to reject the null hypothesis of unbiased forecasts. Several authors have suggested that, as a consequence, the futures market in question is not performing efficiently. If the futures market provides a biased price forecast, then astute traders can profit from that information.

In recent years a few economists have questioned the use of forecast accuracy tests for this purpose. Most recently, Maberly has noted the apparent tendency of futures price forecasts to show less accuracy and greater bias as forecasts further ahead are attempted. He concluded that the existence of forecast bias was due to censoring of the dependent variable (the maturity date price).

In this paper we review the nature and common use of these tests and show that the forecast tests, as often estimated, do tend to show bias. We then examine possible causes for this result and show that it results primarily from a misspecified model. We also show that Maberly's hypothesis does not apply to the usual market tests.

The Forecast Model

Forecast accuracy has commonly been tested by regressing the futures price at maturity (the so-called cash price) on the futures price for the same contract observed at several points prior to contract maturity. The regression is typically specified as:

$$(1) \quad F_{i,t} = a + b\,F_{i,t-n} + e_{i,t}$$

where: $F_{i,t}$ is the futures price at maturity date t for contract i, (alternatively it is a cash market price at time t, C_t; although most studies analyze the futures price at maturity); $F_{i,t-n}$ is the futures price n periods prior to contract maturity date t for contract i; $e_{i,t}$ is the difference between the actual price at maturity $F_{i,t}$ and the price forecast by the regression model. The errors $e_{i,t}$ are assumed to be identically independently normally distributed with mean 0 and variance σ^2. For convenience, we will drop the subscript i, representing individual contracts, from the remaining equations.

The estimates $\hat{a}$ and $\hat{b}$ of the coefficients a and b are obtained from the model by OLS regression. The null hypothesis is that the coefficients a and b are 0 and 1 respectively. If $\hat{a}$ differs significantly from 0, then the futures price is said to have a bias in the level (perhaps due to risk aversion). If $\hat{b}$ differs significantly from 1, then the futures price is said to give a biased forecast of the subsequent cash price.

Past Test Results

The forecast accuracy model has been used to examine the performance of many agricultural futures markets including potatoes and corn (Tomek and Gray), cattle (Leuthold), cattle and hogs (Martin and Garcia), groups of several commodities (Kofi, and Bigman, Goldfarb, and Schectman (BGS)) among many other studies. Nearly always, the estimates $\hat{a}$ and $\hat{b}$ are found to rise and decline respectively, with increasing time remaining to contract maturity. R^2 tends to decrease with increasing time to maturity, and the value of the Durbin-Watson statistic tends to fall. Occasionally, the values of $\hat{a}$ and $\hat{b}$ deviate significantly from the values under the null hypothesis. When this has been observed several of the economists have asserted that the futures market is inefficient. Table 1 summarizes several of these results.

In recent years some economists have become uncomfortable with the result that $\hat{b}$ falls toward 0 with increasing time to maturity, and that market efficiency is often rejected with this test for futures prices far from maturity. Attempts to explain deviations of $\hat{a}$ and $\hat{b}$ from 0 and 1 have been attempted by several authors, most recently Maberly. Maberly suggested that the maturity date prices are censored. He generated random spot and futures prices for a hypothetical commodity, and ran regressions similar to those performed by BGS in an earlier article. Maberly's regressions, like those of BGS, showed R^2 declining as longer forecasts were examined, and the values of $\hat{b}$ and of the Durbin-Watson statistic also declining when longer forecasts were examined.

Table 2 shows estimates of the parameters a and b of this forecast regression, performed for the Chicago Board of Trade wheat and corn, CME cattle, COMEX silver, and CBT T-Bond futures markets, and for a random price sequence of 1000 observations. (See footnote 3 for a detailed explanation of the notation and of the tests performed.) The forecast regressions cover the period October 1980 through February 1988. The regressions were performed in

Table 1

Lag Months (Weeks)	Param- eters	Tomek and Gray Potatoes	Kofi		Leuthold		BGS	Maberly
			Wheat	Potatoes	Cattle	Corn	Wheat	Hypothetical
	a		3.60 (15.0)	59.0 (29.7)	-1.98 (2.20)	4.07 (11.0)	5.93 (7.32)	-0.30 (1.21)
1	b		.99 (.08)	.77 (.13)	1.09 (.08)	.976 (.089)	.94 (.056)	1.01 (.039)
(1-5)								
	R^2		.90	.71	.85	.78	.91	.96
	DW		1.87	2.29	#	#	1.83	2.17
Significance tests			#,#	#,#	#,#	#,#	—,#	—,#
	a	.31 (.39)	3.43 (20.8)	15.1 (37.2)	1.69 (3.93)	17.2 (16.2)	9.72 (13.3)	42.2 (29.7)
2	b	.88 (.17)	.98 (.12)	.97 (.16)	.964 (.144)	.869 (.129)	.91 (.10)	.874 (.092)
(6-10)								
	R^2	.66	.83	.70	.57	.76	.70	.79
	DW	#	2.04	1.96	#	#	1.54	1.87
Significance tests		#,#	#,#	#,#	#,#	#,#	—,#	—,#
	a		12.4 (22.7)	19.0 (45.2)	6.42 (4.52)	31.7 (16.9)	29.2 (20.1)	54.8 (40.6)
3	b		.92 (.12)	.96 (.20)	.795 (.165)	.750 (.133)	.76 (.16)	.833 (.126)
(11-15)								
	R^2		.78	.61	.41	.49	.48	.63
	DW		1.80	2.02	#	#	1.23¢	1.64
Significance tests			#,#	#,#	#,#	#,#	—,#	—,#
	a	.91 (.70)	18.8 (26.1)	84.4 (58.1)	10.3 (4.91)	54.0 (20.5)¢	42.1 (20.8)	101. (52.8)
4	b	.62 (.30)	.87 (.14)	.67 (.26)	.655 (.180)	.572 (.162)¢	.65 (.16)	.69 (.164)
(16-20)								
	R^2	.23	.72	.31	.28	.27	.40	.40
	DW	#	1.92	2.26	#	#	0.61¢	1.15¢
Significance tests		#,#	#,#	#,#	#,#	#,#	—,#	—,#
	a	4.64 (2.79)	55.7 (36.4)	480. (248.)	21.0 (6.47)¢	115. (25.6)¢		109. (50.1)¢
Longest	b	-.99 (1.19)	.66 (.19)	.78 (.19)	.265 (.237)¢	.092 (.200)¢		.66 (.16)¢
	R^2	.05	.44	.06	.04	.01		.40
	DW	#	1.76	1.70	#	#		0.95¢
Significance tests		#,#	#,#	#,#	#,#	#,#	—,#	—,#
	Time	9 mo.	11 mo.	10 mo.	8 mo.	8 mo.	20 wks.	24 wks.

Note: See footnote 3 for explanation of the parameters and tests.

Table 2

Lag weeks	Parameters	Wheat CBT	Corn CBT	Soybeans CBT	Cattle CME	Silver COMEX	T-Bonds CBT	Random Sequence
	n	36	36	43	44	45	31	82
	a	0.05	0.07	0.12	3.85	38.5	1.48	-0.06
		(.12)	(.05)	(.14)	(3.01)	(18.0)¢	(1.50)	(.09)
1	b	.990	.979	.982	.944	.944	.988	1.007
		(.034)	(.017)	(.022)	(.047)	(.020)¢	(.020)	(.012)
	R^2	.960	.990	.980	.906	.980	.989	.988
	DW	2.23	1.57	2.62	2.00	1.86	2.44	1.82
Significance tests		—,—	—,—	—,—	—,—	*,—	—,—	—,—
	a	0.88	0.09	0.77	11.41	93.1	1.01	0.07
		(.18)¢	(.10)	(.33)	(6.89)	(38.4)¢	(3.93)	(.18)
4	b	.737	.959	.880	.834	.877	.993	.995
		(.052)¢	(.037)	(.052)	(.108)	(.043)¢	(.051)	(.023)
	R^2	.854	.951	.874	.585	.906	.928	.958
	DW	1.60	2.13	1.96	1.59	2.05	2.12	2.25
Significance tests		**,—	—,—	—,*	—,—	*,—	—,—	—,—
	a	0.99	0.11	1.30	27.6	193.	3.12	0.31
		(.19)¢	(.15)	(.45)¢	(8.99)¢	(46.9)¢	(5.73)	(.25)
8	b	.692	.945	.779	.580	.731	.969	.954
		(.054)¢	(.055)	(.070)¢	(.142)¢	(.050)¢	(.075)	(.033)
	R^2	.825	.897	.752	.285	.832	.851	.912
	DW	1.68	1.71	1.78	1.05¢	1.82	2.00	1.67
Significance tests		**,—	—,—	**,—	**,**	**,—	—,—	—,—
	a	1.29	0.23	2.18	56.5	158.	6.04	0.51
		(.20)¢	(.20)	(.58)¢	(10.7)¢	(59.0)¢	(6.87)	(.34)
13	b	.603	.892	.634	.124	.757	.936	.930
		(.058)¢	(.073)	(.090)¢	(.170)¢	(.065)¢	(.091)	(.045)
	R^2	.762	.819	.546	.013	.763	.786	.840
	DW	1.62	1.12¢	1.61	0.86¢	1.13¢	1.48	1.59
Significance tests		**,—	—,*	**,—	**,**	**,—	—,—	—,—
	a	1.84	.40	2.35	62.4	473.	15.3	1.05
		(.21)¢	(.31)	(.69)¢	(9.99)¢	(86.3)¢	(10.4)	(.47)¢
26	b	.421	.798	.583	.031	.353	.823	.855
		(.057)¢	(.110)	(.105)¢	(.159)¢	(.092)¢	(.137)	(.062)¢
	R^2	.626	.621	.444	.001	.267	.580	.709
	DW	1.27¢	0.56¢	0.70¢	0.77¢	0.50¢	0.77¢	0.74¢
Significance tests		**,—	*,**	**,**	**,**	**,**	—,**	—,**
	a	2.00	0.73	3.72	61.9	545.	24.4	1.54
		(.21)¢	(.40)	(.76)¢	(10.9)¢	(108.)¢	(12.7)	(.58)¢
39	b	.362	.661	.360	.036	.258	.723	.794
		(.058)¢	(.139)¢	(.113)¢	(.175)¢	(.116)¢	(.170)	(.076)¢
	R^2	.560	.421	.210	.001	.114	.431	.582
	DW	1.10¢	0.42¢	0.50¢	0.78¢	0.29¢	0.35¢	0.49¢
Significance tests		**,—	**,**	**,**	**,**	**,**	—,**	*,**

Note: See footnote 3 for explanation of the parameters and tests.

the manner of the BGS and Maberly studies. Table 2 also includes the values of several test statistics. Note that the value of $\hat{b}$ declines even for non-agricultural commodities and a random series. The fact that the value of $\hat{b}$ falls for a random sequence as well as for several different types of commodity futures suggests that the bias is a consequence of a misspecified model rather than a result of inefficient pricing in those futures markets.

Problems in Test Interpretation

The forecast accuracy tests generally used in the literature contain several problems. First, the tests examine expectations of future prices by regressing outcomes several periods into the future. The information set for the forecasts and the outcomes are different, and differ for forecasts of different lengths of time. The outcome, F_t, is dependent not only on F_{t-n}, but also on the arrival of information in the interim.

If there is no net risk aversion reflected in the futures market prices, no market bias, and interest rates are not stochastic, then the price expected on day t-n for the maturity date t should equal the futures price. That is $E_{t-n}(F_t) = F_{t-n}$, where $E_{t-n}(F_t)$ is the maturity date price expected today. This relationship should hold on each date. Changes in the expected maturity date price and the futures price occur due to randomly arriving new information, so that price changes between days are independent. Futures prices are generally found to follow a random process. (See for example, Anderson, Gordon, or Hudson, Leuthold, and Sarassoro.)

Suppose futures price movements follow a first-order autoregressive process with a root converging to 1 from below. That is:

$$F_t = \rho F_{t-1} + e_t \quad \text{and} \quad \rho \to 1^- \tag{2}$$

Then the appropriate model for testing this hypothesis is:

$$F_t = a + bF_{t-1} + e_t \tag{3}$$

with the null hypothesis H_o: a=0 and b=1. If the tested model is instead:

$$F_t = a + bF_{t-n} + e_t \qquad (4)$$

then the OLS estimate of b and R^2 in equation (4) will decrease as n increases. We illustrate this point as follows. Applying OLS to equation (4) in mean deviation form, we have:

$$\hat{b} = (F'_{t-n}F_{t-n})^{-1}F'_{t-n}F_t \;. \qquad (5)$$

The OLS regression in equation (5) is equal to the empirical estimate of the autocorrelation function between F_t and F_{t-n}. If, for example, $\rho = 0.999$ then we will observe $\hat{b}$ falling as n increases. Furthermore, we can interpret the model (4) as misspecified in relation to model (2) in the context of omitted variables. Rewrite model (2) as:

$$\begin{aligned} F_t &= a + bF_{t-1} + bF_{t-n} - bF_{t-n} + e_t \qquad (6) \\ &= a + bF_{t-n} + b(F_{t-1} - F_{t-n}) + e_t \\ &= a + bF_{t-n} + u_t \end{aligned}$$

where $u_t = b(F_{t-1} - F_{t-n}) + e_t = \sum_{j=1}^{n-1} be_{t-j} + e_t$.

Also $\text{var}(u_t) = (n-1)\sigma^2 > \text{var}(e_t) = \sigma^2$ and $\text{var}(u_t)$ increases and R^2 decreases as n increases. These results follow from the nature of the time series properties of futures price movements assumed in equation (2).

We used a unit root test suggested by Fuller and Dickey and Fuller to test the random walk hypothesis of equation (2) for several agricultural commodities. The results are displayed below.

Tests for a Unit Root in the Autoregressive Process

	Wheat	Corn	Soybeans	Cattle
$\hat{b} = \hat{\rho}$	0.993	0.999	0.999	0.983
$\hat{\tau}_\mu$	-2.73	-1.05	-2.03	-4.02

The $\hat{\tau}_u$ statistic is defined as $\hat{\tau}_u = \frac{(\hat{\rho}-1)}{s_{\hat{\rho}}}$. The significant point for $\alpha = 5\%$ is -3.12 (see Fuller p. 373). The test rejects the unit root hypothesis only for cattle. Even for cattle $\hat{b} = .983$, which is quite close to 1. When the regression (4) is applied to these commodities, the estimate $\hat{b}$ falls as the number of days to maturity increases, as model (2) and the derivation above suggest.

This is not the only problem with several of the regression tests of forecast accuracy reported in the literature. For ease of exposition the derivation above models futures price movements as an additive process. 2/ But, the evolution of futures prices is typically modelled by using a multiplicative random walk. That is, price movements are often assumed to follow a lognormal distribution. The multiplicative process fits actual price movements more closely than the normal process, since prices have a lower bound of 0 but no upper bound. Also, the multiplicative process is theoretically more useful in pricing derivative instruments. (See Samuelson 1965 and 1976, and Black and Scholes.) If the appropriate distribution of futures price movements is the lognormal distribution and forecast models use the normal distribution, then the forecast model is misspecified. Estimates from the model will be biased as will confidence intervals and hypothesis tests.

Several of the forecast models (whose test results are summarized in Table 1) have included observations which overlap in time in order to increase the number of observations in the test. 4/ For example, the futures price in January for the May contract and the futures price in March for the July contract are consecutive observations. Both are four month forecasts. But the forecast errors of both observations are affected by events in April and May. If a bumper crop of soybeans is announced for Brazil in April, outcomes and forecast errors for both contracts are affected by that event. Clearly, this procedure generates autocorrelation among the errors, which creates additional bias downward in the estimates of standard deviation and bias toward significance in the hypothesis tests on a and b. The choice of data creates autocorrelation problems in the articles by BGS, Maberly, and Leuthold, among others. A few of the cited studies avoid this problem by examining only 1 forecast per year (Tomek and Gray, Kofi, Kahl and Tomek). Kahl and Tomek generalize the regression model to observations on several contracts at each observation date. They used the seemingly unrelated regressions technique to estimate the parameters for each forecast regression. But this procedure does not eliminate the major problems with the forecast test discussed above, because each of the forecasts on a given date gives a model with a different amount of time between forecast and outcome.

Maberly attempted to explain the apparent problems with testing forecast regressions as a case of censored dependent variables. If Maberly generated his data with a random walk model (as stated in the article) there is no reason to expect outcomes to be lower than high forecasts and greater than low forecasts. If price movements are drawn from a random normal distribution with mean 0 and standard deviation σ , then the price tomorrow is as likely to be above today's price as it is to fall below it. Maberly suggested that the dependent variable was limited by the forecast model to fall in the range $2.70 \leq C_t \leq 3.74$, where 2.70 and 3.74 were the lowest and highest values, respectively, of the dependent variable in that sample. Other samples would produce different values for C_t. It is incorrect to assert that C_t is constrained to fall within that range, unless such a constraint is imposed a priori. If Maberly had constrained C_t to fall in the range $2.70 \leq C_t \leq 3.74$ (no matter what the forecast price) before conducting the experiment, then the sample would have been censored. However, the a priori restriction that the maturity date price must fall in the range $2.70 \leq C_t \leq 3.74$ while the forecast price can move out of that range is not an accurate representation of the futures markets.

Maberly also found that the Durbin-Watson test statistic fell toward 0 when long forecasts were evaluated. He did not realize that his spacing of "contracts" occurred at 12-period intervals, while his long term forecasts of 13, 20, and 24 periods contained overlapping periods leading to autocorrelation in the errors.

Table 2 shows several forecast regressions performed in the same manner as those by BGS and Maberly, and which are quite similar to those performed by several other authors. Note that $\hat{b}$ declines with increasing forecast length for every commodity and for the random sequence. Also, $\hat{a}$ increases, R^2 declines, and the Durbin-Watson statistic falls for long forecasts as opposed to short ones.

Alternative Evaluation Techniques

The efficiency of futures prices has been tested in many ways. Tests other than the regression test of forecast accuracy are not affected by the results of this paper. Several authors have performed tests other than the unit root test used in this paper. Several tests of randomness and distributional form are described in Anderson, Gordon, and Hudson, Leuthold, and Sarassoro. Comparison tests of forecasts are performed by Marquardt and Just and Rausser. Kolb and Gay present a useful alternative to forecast accuracy regression tests and apply it to the cattle futures market. They test that the means of each of the daily price changes between forecast and outcome are zero.

Conclusion

Many economists have performed regression tests of the forecast accuracy of futures prices. These studies often found the parameter estimates $\hat{a}$ and $\hat{b}$ to differ significantly from 0 and 1, respectively. On the basis of these test results several authors have concluded that several futures markets price commodities inefficiently.

This paper has shown that the forecast bias is consistent with the use of a misspecified model rather than a result of pricing inefficiencies in the futures markets. The significant difference of the parameter estimates $\hat{a}$ and $\hat{b}$ from 0 and 1, respectively, should be reasons to reject the joint test of the model and efficiency rather than the hypothesis of pricing efficiency. Several alternative tests of market efficiency are available, and can be used by economists examining market performance.

We have also described other factors which will also lead to bias in the forecast accuracy regressions. In particular, using overlapping observations will generate autocorrelated errors and will bias standard errors downward and t-statistic values upward.

Because of these sources of bias in the standard regression test of forecast accuracy it should be abandoned. Alternative techniques which take into account the nature of futures price movements provide a clearer picture of the efficiency of these markets.

Footnotes

1/ Pope and Hallam asked the following question: "64. Because information changes with time, the price generated by the futures market is a poor predictor of the future cash price." The responses were SA (Strongly Agree) = 5.3%, A = 33.1%, D (Disagree) = 39.6%, SD=8.2%, DK (Don't Know) =13.9%. However, a large majority of those responding disagreed with the related statement: "15. Given current information, the futures market is not a good indicator of expected supply and demand conditions." The responses were SA=4.1%, A=19.6%, D=49.0%, SD=15.5%, DK=11.8%.

2/ A similar derivation can be performed for a process that is linear in the logs.

3/ Notes for the tables: $\hat{a}$ and $\hat{b}$ are the estimates of the parameters of the regression:

$$F_t = a + bF_{t-n} + e_t.$$

Where: F_t is the price of the contract at maturity.
F_{t-n} is the price of the contract n periods before maturity, n is expressed in months or weeks, depending on the author, and e_t is the regression residual.

R^2 is the coefficient of determination.
DW is the value of the Durbin-Watson statistic.
# indicates that no value of a given statistic was reported in that study.
The numbers in parentheses are the standard errors of the estimates.

"Significance tests" indicates whether or not the statistics for two tests were significant at a 95 percent confidence level (*) or at a 99 percent confidence level (**), were not significant at those levels (--), or were not conducted in that study (#). The two tests were:

1) whether or not the F-statistic for the joint null hypothesis that a,b=(0,1) was significant, and
2) whether the Q-statistic for the null hypothesis that autocorrelations for lags 1 through 24 were equal to 0 was significant.

¢ indicates that the t-statistic rejects the null hypothesis that a=0 or that b=1 at a 95% confidence level.

In Table 2, Random shows the results from regressing F_t on F_{t-n} when F_t and F_{t-n} are both generated from a pseudo-random process (SAS RANNOR function) similar to that performed by Maberly. 1100 observations were generated, and the first 100 discarded. The drawings were normal with mean 0 and standard deviation 20¢. Price was initialized at $6.00. See Maberly for further details on the procedure.

4/ Kahl and Tomek stress this problem and its consequences in their article.

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