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Analysis of Expected Price Dynamics Between Fluid Milk Futures Contracts and Cash Prices for Fluid Milk

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Introduction and Objectives

Reduced levels of government intervention in the pricing of dairy products coupled with relatively low farm gate prices and substantial price volatility have resulted in a business environment in which dairy industry participants need to find alternative ways to manage price risk. The Coffee, Sugar, and Cocoa Exchange, Inc. (CSCE) responded to changes in the dairy industry by launching futures contracts on Cheddar Cheese and Nonfat Dry Milk in 1993. The initial expectation was that the correlation between cheddar cheese prices and fluid milk prices was high enough that cross-hedging opportunities for milk in the cheese contract would encourage hedging activity by both cheese manufacturers and firms involved in the trade of fluid milk.[1] To date, however, there appears to be little futures pricing activity by individuals engaged in the trade of fluid milk. As a result, both the CSCE and the Chicago Mercantile Exchange (CME) in 1995 petitioned the Commodity Futures Trading Commission to begin trading a futures contract in fluid milk. Milk futures were introduced in December 1995 at the CSCE, and January 1996 at the CME. These provide markets in which producers and bottlers of fluid milk can hedge the output price of their product directly. In addition, manufacturers who use fluid milk in the processing of cheese and soft dairy products (yogurt, ice cream, etc.) can directly hedge the future value of their primary input.

An important part of developing a sound and successful hedging program for any commodity is understanding the underlying fundamental relationships between cash and futures

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[1] In this paper "fluid milk" refers to raw producer Grade A milk rather than Class I or Beverage use milk.

markets, and being able to use that information to derive accurate forecasts of cash/futures basis levels (basis is the difference between the cash price at a specific location and the futures price for a particular delivery period). It is critical that economic agents in the cash market understand how price sensitive information is transmitted between cash and futures markets if they are to successfully use futures markets for price risk management.

The objective of this study is to provide an empirical evaluation of the expected relationship between cash and futures prices for fluid milk. This is done using historic cash prices from 1988 to 1995, and making inferences about how futures prices would have behaved if they had traded during this sample period. Futures prices are simulated over the sample period based on two assumptions about futures market behavior for fluid milk. The first is that the futures market will essentially price the Basic Formula Price (BFP).[2] The BFP is an estimate of the previous month's pay price for Grade B manufacturing milk in Minnesota and Wisconsin adjusted for contemporaneous changes in the prices of manufactured milk products. It establishes the federal milk marketing order minimum Grade A pay price for Class III milk used to make cheese, and is the mover of both the minimum Class II price for milk used in soft manufacturing products and the minimum Class I price for beverage milk (Jesse).

The second assumption is that the futures market for fluid milk will reflect actual fluid milk pay prices received by producers in the Chicago Regional Order. Actual producer pay prices for fluid milk in the Chicago order differ from the BFP based on milk utilization, and

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[2] The Basic Formula Price replaced the Minnesota-Wisconsin price (referred to as the MW). The MW derived the pay price of Grade B milk based on estimates from plant surveys. The BFP differs from the MW in that it uses a product price formula for cheese, butter, and nonfat dry milk to derive a change in the value of manufacturing milk. Although the MW and BFP differ month to month, there is little difference in their average annual values.

differ from other marketing orders' pay prices based on differences in milk utilization and a transportation differential based on distance from Eau Claire, Wisconsin. These issues are discussed in more detail below.

The Upper Midwest federal order is chosen for analysis because the region has historically been a major milk producer in the United States. Further, more than 90 percent of its Grade A milk is regulated under the federal marketing order system. It also represents a cash market which is in close proximity to the delivery area for the fluid milk futures contract.

California is chosen for analysis because it currently represents the largest single producer of milk, and is unique in that its Grade A milk is not regulated by a federal marketing order, but rather by its own state order. This suggests that California is the market that may face the greatest basis risk in utilizing the fluid milk futures contracts as risk management vehicles since the futures contracts are designed to price milk within the federal order system.

Importance of Basis Relationships

The basis between a commodity's futures price for a specific delivery month and its cash price at a specific location is a reflection of the differences in the supply/demand relationships existing in the two markets. The futures price is generally interpreted as a measure of a commodity's value in the national market (i.e., some composite of all local markets) while the price in a specific cash market is a measure of value locally. As conditions in one market change relative to the other market one would expect a change basis. However, as long as arbitrage is allowed between the two markets, basis levels will be constrained by the transactions costs of moving the commodity between the cash and futures markets. If the difference between the current cash price in some local market and the futures price for an expiring contract are more than the transport costs between the markets, the commodity will be bought in the cheaper market and transported to the higher priced market. As long as there are no physical restrictions on movement, this activity will bring the basis back to a level which is at most equal to transport costs suggesting that on margin there is no systematic profit associated with trading between the two markets. If markets are structured such that arbitrage is possible between futures and cash markets, basis relationships will be more predictable than flat price in either market. Any new market information will affect futures and cash markets similarly. While the exact magnitude of price change in futures and cash market may not be identical following new market information, the difference between the markets will tend to be limited to the costs of moving between the two markets.

The costs of moving between markets may be associated with geographical location in the case of futures contracts and cash markets with different delivery points, or temporal costs in the case of cash and futures contracts calling for different delivery periods. If basis is predictable, then futures prices for later delivery dates can be "localized" by being adjusted for the expected basis which will exist at contract expiration. This allows the futures market to serve as a price discovery center for the cash market, and to serve as a risk management vehicle for participants in cash markets by way of hedging.

As noted by Purcell, futures hedging as a vehicle for avoiding cash price risk will only be effective if two conditions are met:

1) Cash and futures prices must respond to the underlying forces of supply and demand in such a way that the two market tend to move together, and

2) As the maturity date of the futures contract approaches the cash and futures prices

must converge to some predictable basis.

If the above conditions are not met then the futures market does not provide risk management opportunities for cash market participants. It is therefore critical to identify the expected basis relationship between cash and futures markets before employing futures contracts as part of a marketing strategy focused on managing price risk. This provides a particular challenge for new futures contracts which do not exhibit an historical track record from which to construct the basis relationship.

Futures Market Price Simulations for Fluid Milk

The fluid milk futures contract specifications call for delivery of Grade A raw milk in the Midwest. More specifically, the delivery location must be in the Madison District of the Chicago Regional Marketing Order (CSCE). Based on this, two different futures pricing scenarios for milk are considered.[3]

The first futures pricing regime assumes that the futures market prices the Class III BFP price. The fluid milk contract designed by the CSCE was constructed to reflect BFP pricing.

The formula used to calculate the BFP series was changed in early 1995. As a result the new price formula is used to re-calculate the BFP since 1988 in order to consider prices which would have existed under the new pricing regime. Figure 1 shows the relationship between the BFP using the new and old pricing formulas. From figure 1 it can be seen that the old and new pricing formulas result in similar prices, especially since mid 1990.

The second futures pricing regime considered accounts for the fact that the cash price

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[3] There are differences in the design of the futures contracts at the CSCE and the CME. While this analysis focuses on the CSCE contract for fluid milk, the results are not sensitive to the differences in contract specifications between the two exchanges.

actually received in the Chicago order by a producer or merchandiser is a function of minimum class prices and milk utilization. The prices considered here assume that the futures market will focus on the fluid price in the Chicago cash market taking into account the average annual utilization factors in the Chicago order. Under this scenario the price is determined by the percentage of delivered milk used as Class III (cheese, butter, and non-fat dry milk) multiplied by the current month BFP price, plus the percentage of delivered milk used as Class I (beverage) and the percentage used as Class II (soft dairy products) multiplied by the BFP price from two months previous.[4] In addition, the price is adjusted for a Class II differential of 30 cents based on Class II utilization and a Class I differential of $1.40 for the Class I use.[5] The utilization rates change slightly each month. To construct prices based on utilization rates, average annual utilization rates in Chicago were calculated for 1988 through April 1995. These were then multiplied by the BFP which would have existed each month using the new BFP price formula and then adjusted for the class differentials to arrive at monthly fluid prices for Chicago from January 1988 to April 1995. Since the futures market is a physical delivery market, it may be reasonable to assume that the futures market will more closely track the pay price based on utilization rather than the actual current BFP. For the purposes of this analysis, the price series calculated using average annual utilization rates is referred to as synthetic futures.

Figure 2 compares the constructed prices from both the BFP and the synthetic futures price regimes. The average annual utilization weights used to calculate the synthetic futures are

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[4] Actual prices received for Class I and Class II milk are based on the BFP from two months previous.

[5] As of December 1994 skim milk used to make nonfat dry milk was moved into Class III-A. The minimum Class III-A price is determined by a nonfat dry milk product price formula. The price is lower than the Class III price, but since less than 4 percent of the milk in the Chicago order is used in this class the impact is minimal.

listed in Appendix A. Note from figure 2 that the prices from both futures price scenarios track very closely.

Price Relationships

Table 1 presents the correlation coefficients between the MW based on the old price formula, the BFP from the new formula, the synthetic futures price, and the Grade A cash prices actually received in the Upper Midwest and California markets over the sample period considered.[6]

While the correlation coefficients provide evidence of a high degree of linear co-movement between the prices considered, they do not provide evidence of causality or any measure of price dynamics. However, the higher the correlation coefficient between two price series the more confident one can be that the two prices will respond in a similar manner to new market information that may become available. It is important to observe a high degree of correlation between cash and futures prices if the futures market is to serve as an effective risk management vehicle for cash market participants. Based on the correlation coefficients in table 1, it appears that hedging opportunities will exist in both cash markets regardless of which futures price scenario is considered.[7] The lower correlation between the California Grade A price and the two simulated futures prices relative to the Upper Midwest correlations suggest

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[6] Correlation coefficients measure the linear relationship between two variables. The coefficients can range between -1 and 1. A high absolute value of the correlation coefficient suggests that the two series being considered show a high degree of co-movement.

[7] These results actually understate the relationship which will likely exist once the cash market adjusts to the new BFP pricing formula. If the BFP price and the synthetic futures were replaced by identical variables calculated using the old MW price formula, the correlations would be higher. This can be seen by examining the correlation coefficients between the cash prices and the MW using the old MW pricing formula in table 1. For example, the correlation between the Upper Midwest price and the MW calculated using the old pricing formula is 0.9818.

California hedgers may face greater basis risk than hedgers in the Upper Midwest.

Examination of Price Dynamics

In this section a more rigorous examination of the relationships between the two futures price scenarios and actual prices for Grade A milk in the Upper Midwest and California are investigated.

The first step in investigating price dynamics is to test whether the prices considered behave as stationary or non-stationary processes.[8] Stationarity is tested using the Augmented Dickey-Fuller unit-root test (the test and associated results and critical values are outlined in Appendix B: Technical Appendix). Stationarity is an important consideration because if the data are non-stationary then results from traditional statistical models are suspect. This, in turn, affects the way one ought to test for causality between the variables being considered.

Based on Augmented Dickey-Fuller tests, we cannot generally reject the null hypothesis that the prices considered behave as stationary processes. As a result, bivariate vector autoregressive models (VAR) using logged price levels are estimated to explore the specific pricing relationships and associated dynamics between the cash prices for fluid milk in California and the Upper Midwest, and each of the two futures pricing scenarios considered. For a complete explanation of the VAR technique, see Appendix B. Results of the VAR regressions are then used to test for Granger causality between cash and the simulated futures prices. The Granger causality tests are also outlined in Appendix B.

Based on the results of the estimated VAR models, the relationships described in table 2

[8] A time series of data is said to be weakly stationary when its mean and variance do not change over time, and the covariance of values generated at different points in time depend only on the time interval considered, and not on time itself.

are suggested. The results indicate that there is instantaneous Granger causality between the synthetic futures prices and both cash markets. In addition, there is Granger causality from both cash markets to the synthetic futures prices with the cash price impact being felt for up to two months. Note that causality does not run from the synthetic futures prices to the cash prices. This suggests that the causal impact of a change in the futures price is completely incorporated into the cash market within one month. The finding that changes in synthetic futures prices are immediately (i.e. within one month) reflected in the cash market implies that the basis in both California and the Upper Midwest will adjust immediately to shocks in the futures market. This implies basis risk is less than would be expected if cash price changes lagged changes in futures prices. The finding of significant instantaneous Granger causality reinforces the correlation results which suggest a strong market link between the cash and synthetic futures price series.

If the futures market focuses on the Class III BFP price rather than the Chicago blend price, results change very little with respect to price dynamics. As seen in table 2, the causality tests still show instantaneous causality between futures and cash, and no delayed cash response to futures prices. One unique result of a futures market which prices BFP is that the Upper Midwest cash price continues to influence futures for up to four months, rather than two. However, from the standpoint of hedging effectiveness the more important result is that cash price changes, and thus basis levels, do not lag changes in the simulated futures price.

Examination of Basis Relationships and Seasonality

The analysis presented thus far provides evidence that the futures market, whether it prices the BFP or the expected Chicago blend price (synthetic futures), will exhibit a close relationship with the Grade A cash prices in the Upper Midwest and California. In this section the expected basis relationships between the two Grade A cash prices and the two futures price scenarios are presented. Figures 3 through 8 show the average monthly basis levels for the sample period January 1988 through April 1995.

Figures 3 and 4 illustrate expected basis relationships in the Upper Midwest under both futures price scenarios; figure 3 assumes the futures market prices the BFP price, and figure 4 assumes the futures market prices the expected Chicago blend price. Basis is calculated as cash price minus the simulated futures price. The middle line in figures 3 and 4 represent average monthly basis, with the upper and lower curves illustrating average monthly basis plus and minus one standard deviation. Notice that the overall basis pattern estimated for the Upper Midwest is not particularly sensitive to the futures price scenario considered (this was anticipated based on figure 2). There does appear to be an identified seasonal pattern to the Upper Midwest basis. In general, the basis level weakens from January through April, and then steadily increases through the remainder of the year until December.[9] Basis peaks in October or November with the cash price exhibiting a 30 to 50 cent premium per hundred weight over futures, depending on which futures price scenario is considered. The standard deviations illustrated in figures 3 and 4 provide some measure of the basis risk which will be faced by hedgers in the Upper Midwest. Basis risk appears to be smallest in the March, April and May period, which is associated with the weakest expected basis levels. As basis strengthens, basis risk appears to increase with the greatest basis risk being experienced in the months of August and September.[10] Figure 5

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[9] Basis is considered to be weaker the lower the cash price is relative to futures, and strengthens as the cash price gains on futures.

[10] This basis pattern is what one would expect given production and consumption patterns in the milk industry. The relatively weak spring basis is associated with the spring flush, and the strong basis late in the year corresponds to the relatively strong holiday season demand for dairy products.

provides a direct comparison of the expected Upper Midwest basis conditions under the different futures price scenarios. The basic seasonal basis pattern appears invariant with respect to pricing regime, but the synthetic futures scenario reveals a weaker basis by about 30 cents per hundred weight throughout the year.

The expected basis relationships in California are substantially different than those expected for the Upper Midwest. These are illustrated in figures 6, 7 and 8. Note that there is no well defined seasonality to the California basis. In addition, the basis risk as measured by the standard deviation of expected basis appears to be substantially larger than the basis risk faced by producers in the Upper Midwest. This is as expected, however. As noted earlier, California represents a milk market which is separate from the federal regional marketing orders. As such, one would expect a greater measure of dispersion between fluid prices in California and prices determined in the Chicago order based on the BFP Class III price.

It is also interesting to note that the general expectation is for California cash prices to consistently trade at a discount to futures regardless of which futures price scenario is considered. This is in contrast to the Upper Midwest where the cash price paid to producers is expected to represent a premium to futures most of the year. This is because the California State Order prices manufacturing milk below the BFP price.

The results of this section support the suggestion based on the correlation coefficients in table 1 that hedgers in California will likely face more basis risk than hedgers in the Upper Midwest. The exception is in summer months when both markets exhibit a standard deviation of anticipated basis in excess of 55 cents per hundred weight.

Hedging Effectiveness

Hedging is the trading of flat price risk for basis risk. For hedging to be an effective risk management strategy the potential hedger must be convinced that basis risk is less than price risk. Figures 9 and 10 compare the standard deviations of monthly Grade A milk prices in the Upper Midwest and Chicago with the monthly standard deviations of expected basis associated with the two futures pricing regimes considered. From figure 9 it is clear that potential hedgers in the Upper Midwest can reduce their market exposure substantially by utilizing a futures market hedge based on either futures price scenario considered. The standard deviation of expected average monthly basis, with the exception of September, is consistently less than half of the standard deviation of price for the period January 1988 to April 1995.

Figure 10 reveals a different situation for California producers. For most parts of the year California producers face a basis risk which is not much different than the flat price risk they face given the two futures price scenarios considered. The exception is late in the year when there appears to be a substantial reduction in market risk associated with trading flat price risk for basis risk. It is interesting to note that the overall basis risk faced by California market participants is not much greater than that faced by the Upper Midwest. What is different about the California market is that it appears to exhibit significantly less overall price risk than the Upper Midwest. However, this result does suggest that the benefits associated with seeking risk management opportunities through a futures market hedge are greater for a Midwest market agent than one doing business in California. Price risk in the California market, based on the sample period considered, appears to be greatest in the final quarter of the year. This is also the period in which expected basis risk is the lowest, and hedging opportunities do appear to be attractive in this time period. Based on figure 10, it appears that market risk in California can be reduced by almost half in the last quarter of the year utilizing a futures hedge based on the futures price scenarios considered.

Actual Basis Performance

Futures contracts on fluid milk began trading at the CSCE ib December 1995, and the CME in January 1996. Figure 11 shows the actual monthly average monthly nearby[11] futures contract prices from January through November 1996 at the CSCE compared to the prices which would have existed under the two pricing senarios considered in the empirical analysis earlier. Note that the first four months of the year the futures market tracked very closely the BFP. Any hedges placed for delivery in that time period uising the basis expectations generated in the anlysis here would have yielded a net selling or buying price very close to thast anciparted based on the simulated BFP fiutures prices.

Over the summer months the actual futures prices traded at a significant premium to the prices which would have been expected given the simulated futures pricing formulas used in the empirical analysis. However, this is most likely do to the unique factors surrounding milk production in 1996 rather than the futures market moving toward some new refernce price. Prices in Kune through Spetember were unusual in that milk production was down nationally, the Southeast was very short of Grade A milk for Class I use through Spetember and had to purchase milk from outside the region. The supply source was Wisconsin (in the Upper Midwest pricing order). However, Wisconsin manufacturing plants were reluctant to give up locally produced milk because Wisconsin production was also down and the milk was needed to maintain efficient operation of the cheese plants so that committments to cheese buyers could be met. Cheese

[11] The nearby contract is the one closest to maturity.

plants were only willing to relenquish milk if they were paid a siubstantial "give up" premium averafging between $3 to $5 per hundredweight. This is roughly the difference between the actual futures prices traded at the CSCE and the futures prices implied by the BFP and synthetic futures senarios. As noted from Figure 11, by late fall the actual futures prices had returned to a level consistent with the synthetic futures price, and is likely to return to a level near the BFP in early winter. It should be noted that the milk market is not the only agricultural market which experienced futufres porices trading at abnormal premiums to cash markets. The 1996 corn makret, for example, exprienced abnormally strong basis levels in the late summer as well. In many parts of the upper midwest (i.e., Wisconsin) cron basis levels in July sand August were as much as $1 per bushel stronger than would normally be the case in that time of year.

Figure 12 shows the basis levels actually experienced in the Uppoer Midwest in 1996 by month relative to the basis levels predicted in the empirical analysis. Note that basis levels are quite close to predicted levels with the exception of the summer months. As noted above, however, the summer of 1996 is most likely an aberation and not indicative of the overall accuracy of the basis forecasts genertaed earlier.

Conclusions

This study has examined the potential opportunities for risk management in milk markets afforded through the introduction of a fluid milk futures contract. The study considers two cash markets, California and the Upper Midwest, and two futures price scenarios. The first futures scenario assumes that the futures market prices the BFP Class III price. This was the intent of the original futures contract design. However, it is suggested that futures traders may instead focus on the Chicago blend price since the futures contract is designed to allow for physical delivery.

The Chicago blend price may be more representative of an actual cash market price since it is the BFP formula price adjusted by Class I and II differentials based on average annual milk utilization .

Results based on several tests suggest that there will be a strong relationship between the futures market, regardless of which futures price scenario is considered, and Grade A milk prices in both cash markets. However, the relationships appear much stronger for the Upper Midwest. This is not surprising since the BFP is explicitly used to establish prices in the federal marketing order system. The Upper Midwest is part of the federal order system, and California is not. The result is that market agents in the Upper Midwest may be able to reduce their market risk by as much as half through a futures market hedge. Similar hedging benefits would be expected in other federal milk marketing orders as well. This is because all federal orders rely on the BFP to determine minimum milk prices. For California market agents, hedging opportunities of the magnitude described above will likely be available in the latter months, but hedges for delivery early in the year may not have a substantial impact on market exposure.[12]

[12] The results here are partly a function of the current milk pricing environment resulting from government involvement in milk markets. While it is safe to assume there will be changes in the milk marketing system in the near future, it is currently not clear what exact form the changes may take.

Table 1. Correlation matrix for various milk prices, January 1988 through April 1995.

	Upper Midwest	California Blend	Synthetic Futures	BFP	Old MW
Upper Midwest	1.0000				
California Blend	0.8777	1.000			
Synthetic Futures	0.9089	0.7794	1.000		
BFP	0.9160	0.7844	0.9742	1.000	
Old MW	0.9818	0.8752	0.9272	0.9278	1.000

Table 2. Granger Causality tests between various milk prices, January 1988 through April 1995.

	Synthetic Futures				BFP			
Cash Prices	G1[1]	G2[2]	G3[3]	LAG[4]	G1	G2	G3	LAG
Upper Midwest	YES	YES	NO	2	YES	YES	NO	4
California Blend	YES	YES	NO	2	YES	YES	NO	2

1. Indicates instantaneous Granger causality.
2. Indicates causality from cash to futures.
3. Indicates causality from futures to cash.
4. LAG is the number of lags chosen based on a likelihood ratio test for a bivariate model.

All residuals were white noise based on the Q-statistic at 9 lags.

Figure 1. Old MW vs. New BFP Milk Prices.

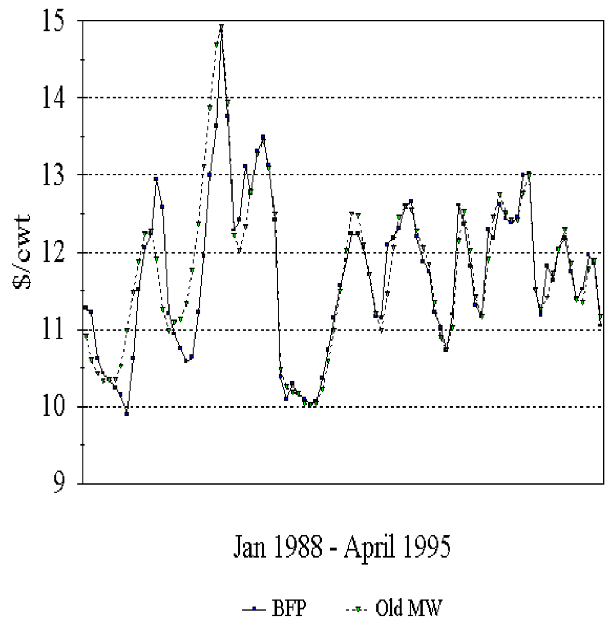


Figure 2. BFP Price vs. Synthetic Futures.

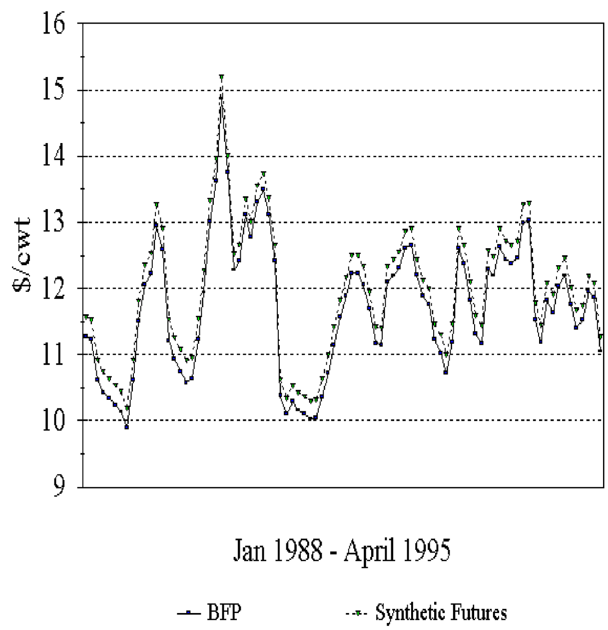


Figure 3. Expected Average Upper Midwest Basis Assuming the Futures Market Prices the BFP.

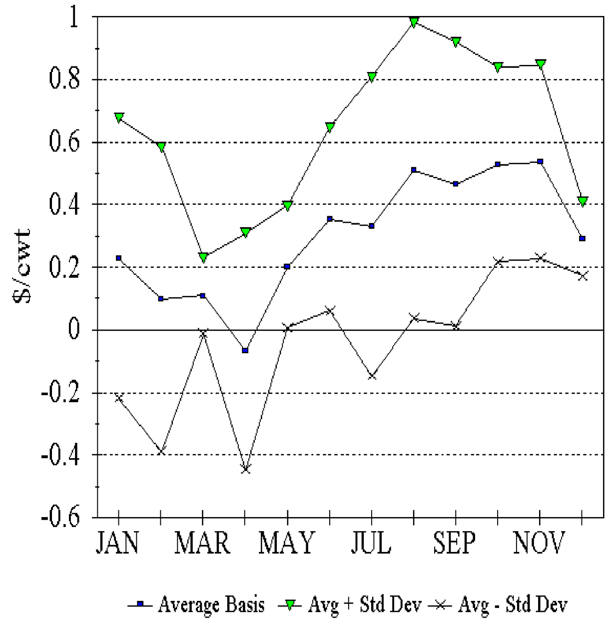


Figure 4. Expected Average Upper Midwest Basis Assuming the Futures Market Prices the Synthetic Futures.

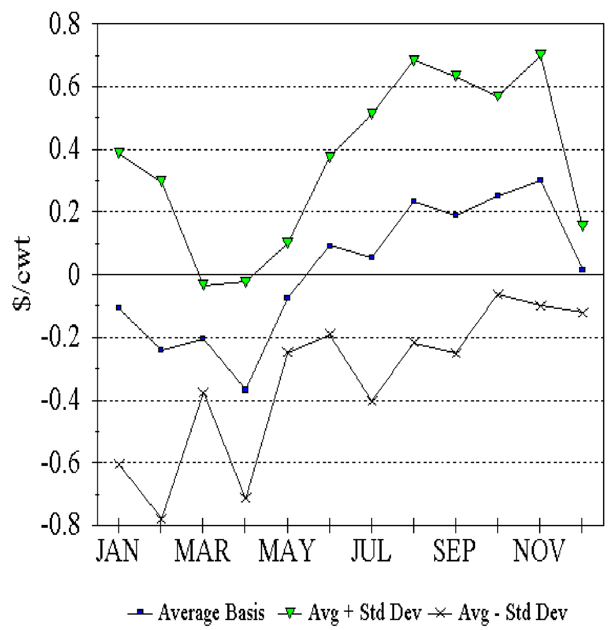


Figure 5. Expected Upper Midwest Basis Based on BFP vs. Synthetic Futures.

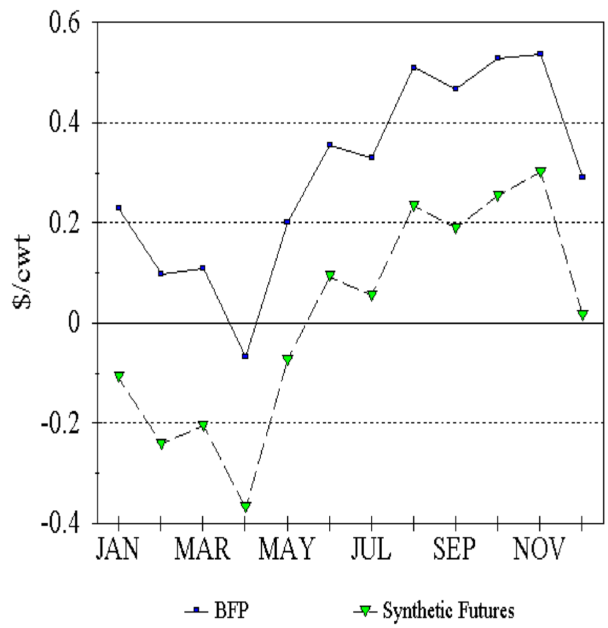


Figure 6. Expected Average California Basis Assuming the Futures Market Prices the BFP.

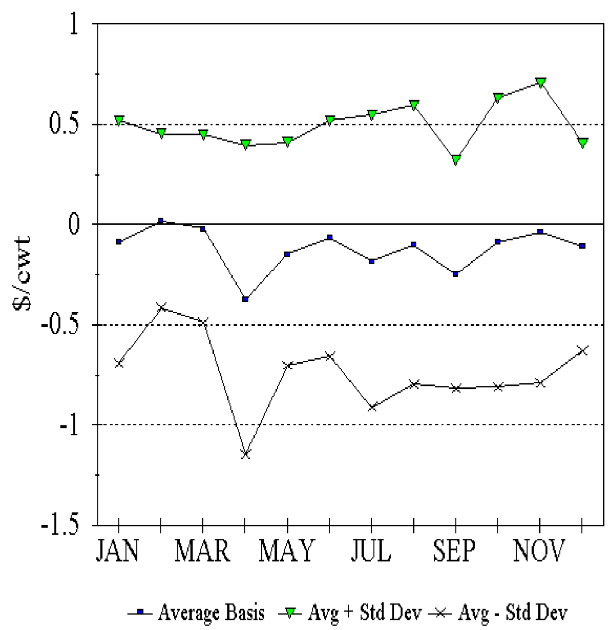


Figure 7. Expected Average California Basis Assuming the Futures Market Prices the Synthetic Futures Price.

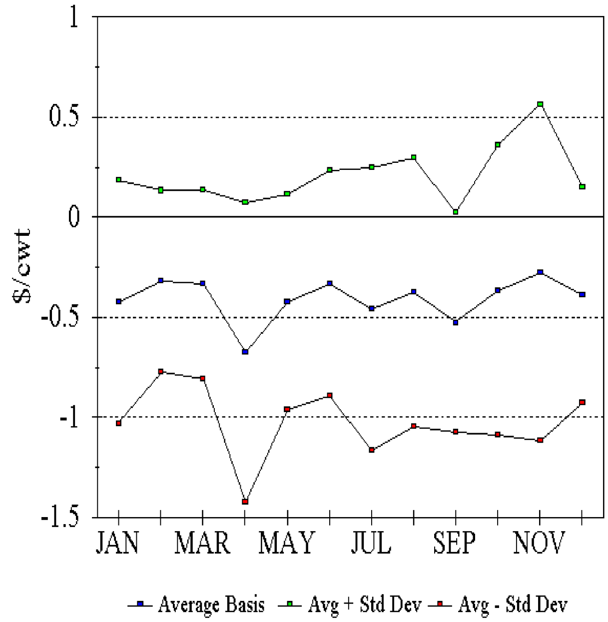


Figure 8. Expected California Basis Based on BFP vs. Synthetic Futures.

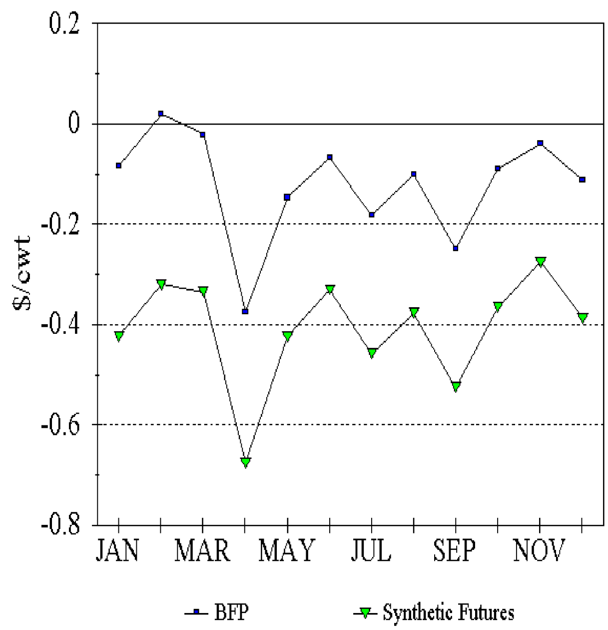


Figure 9. Standard Deviation of Upper Midwest Grade A Price Relative to Standard Deviation of Expected Basis.

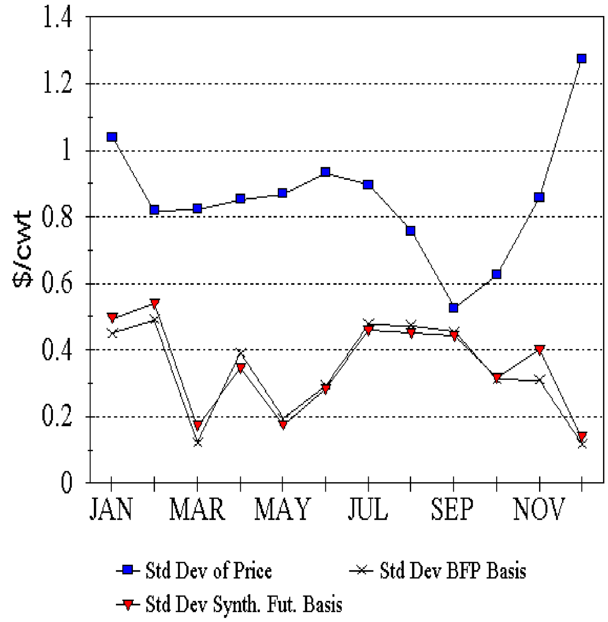


Figure 10. Standard Deviation of California Grade A Price Relative to Standard Deviation of Expected Basis.

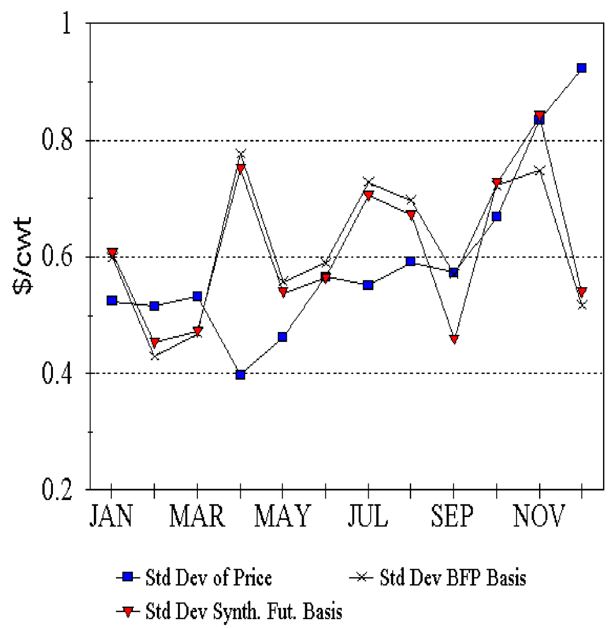


Figure 11. Actual Monthly Average Milk Futures Prices Compared to Simulated Prices - 1996.

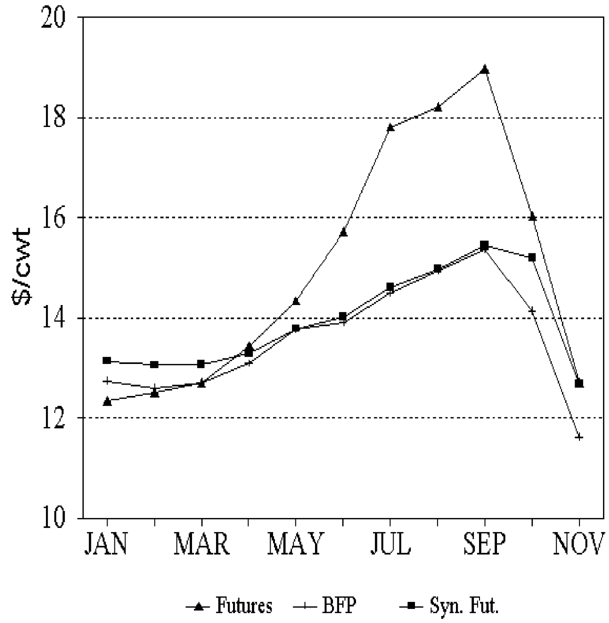
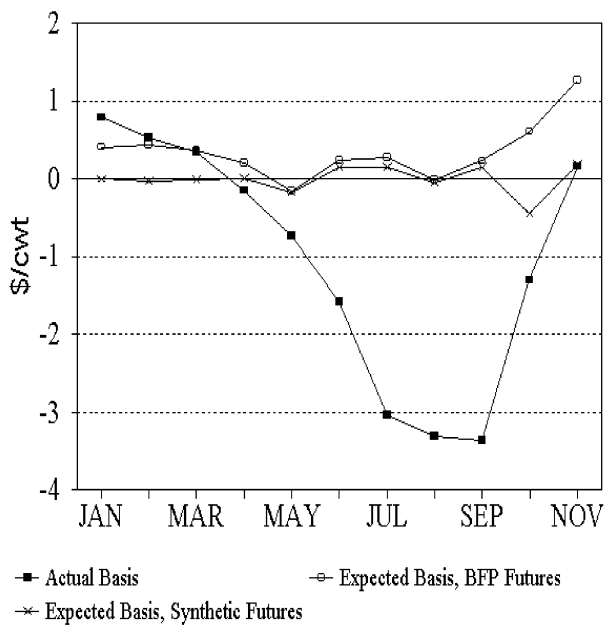


Figure 12. Actual versus Expected Monthly Milk Basis Levels - 1996.



Appendix A. Average annual milk utilization rates, Chicago Regional Order, 1988 - 1995.

	Class III	Class II	Class I
1988	72.8	8.1	19.8
1989	70.4	8.2	21.4
1990	77.6	6.0	16.4
1991	75.4	6.4	18.2
1992	78.6	5.2	16.2
1993	75.0	6.2	18.8
1994	75.9	6.3	17.8
1995*	79.5	5.4	15.1

* Through April.

Appendix B: Technical Appendix

Stationarity Tests

The first step in identifying the dynamic relationship between two data series is to determine whether the series behave as stationary or non-stationary processes. There are several tests available for testing stationarity. This study employs the Augmented Dickey-Fuller test for unit roots. A test for a unit root is a test to determine whether the data being considered are stationary (meaning that the mean and variance of the data are not a function of time), or whether the data must be differenced in order to behave as a stationary process. If the data are stationary, they are said to be integrated of order zero, denoted I(0). If the data must be differenced to behave as a stationary process, they are said to be integrated of an order equal to the number of times they must be differenced to behave as a stationary process. For example, if they need only be differenced once to exhibit a mean and variance which do not change with time, they are integrated of order one. For most economic data, a first difference is sufficient to transform non-stationary data to a stationary process. Thus, most stationarity tests in economic analysis are tests of whether the data are I(0) or I(1).

The results of a stationarity test have significant implications for the way in which data should be modeled statistically. If data are stationary the series will tend to be erratic, but will over time return to its mean level. In this instance one can have confidence in traditional statistical measure of goodness of fit and significance of individual parameter estimates. A casual observation of figures 1 and 2 in the main body of the paper show the prices considered to continually cross a horizontal axis equal to the mean value of the series. The Augmented

Dickey-Fuller test represents a more rigorous test of whether the data used represent stationary processes.

The basic formulation of the Augmented Dickey-Fuller unit root test used in this study is specified in the regression:

$$(1) \qquad y_t - y_{t-1} = \mu + \lambda y_{t-1} + \sum_{j=1}^{p} \gamma_j \; \Delta y_{t-j} + \epsilon_t$$

where y represents each of the price series being studied. This regression is estimated and the traditional t statistic for significance of λ is calculated. The t-statistic is then compared with the special critical values constructed by Dickey and Fuller to determine significance. If the t statistic is larger than the critical value at the desired level of significance, then it suggests that y explodes over time. This, in turn, implies y is non-stationary, and exhibits a unit root.

Results of Augmented Dickey-Fuller tests for the various milk prices considered in this analysis are presented in table B1. All tests of the data were conducted in logs.

Note that in most all cases the t-statistics calculated with the regression test described above result in a failure to reject the null hypothesis of stationarity at the 10 percent level. One exception is the blend price in California. However, subsequent tests of the performance of the California series suggest that over most of the data period, the California price does behave as a stationary series. For example, the unit root test was re-estimated for California over the sample period January 1990 through April 1995, and the test fails to reject the null hypothesis of stationarity. As a result, the price dynamics tests described below are conducted assuming all prices considered exhibit stationarity.

Tests for Price Dynamics

Based on the stationarity tests above, it was determined that price dynamics can most appropriately be explored using logs of the price levels of the various series in a set of bivariate Vector Autoregressive (VAR) models. The basic formulation of a VAR model is of the form:

$$(2) \qquad \mathbf{y_t = \mu + A_1 y_{t-1} + ... + A_p y_{t-p} + \epsilon_t}$$

where **y** and ϵ are vectors of random variables (here the y's are the various milk prices), $\boldsymbol{\mu}$ is the vector of the means of y, and **A** is a matrix of parameters to be estimated. For the purposes of this analysis, the above equation is augmented with the addition of monthly dummy variables. These are included to account for seasonality in both the production of milk and the consumption of dairy products.

The VAR can actually be viewed as a set of individual regression models with identical regressors. For example, one model would specify the Upper Midwest blend price as a dependent variable which is regressed on lagged values of itself and lagged values of the synthetic futures price. Another equation in the system would specify the synthetic futures price as a dependent variable and regress it on lagged values of itself and values of the Upper Midwest blend price. This is done for all pairs of cash prices with synthetic futures, and all pairs of cash prices with the BFP series. For a more complete discussion of VAR estimation, see Green.

By estimating the VAR models described above, the direction of causality between various prices can be tested. This is done by applying Granger's causality methodology to the bivariate VAR models described above. Granger causality is identified when the lagged values of one variable, say the synthetic futures price, has explanatory power in the regression of a different variable, say the Upper Midwest cash price, on lagged values of the Upper Midwest cash price and the synthetic futures price.

For example, if we specify a single equation from the system described in equation (2) we would have:

$$(3) \qquad y_{1t} = \mu + \sum_{j=1}^{n} A_{1j}\, y_{1,t-j} + \sum_{j=1}^{n} A_{2j}\, y_{2,t-j} + \epsilon_{1t}$$

where y_1 is the Upper Midwest blend price for milk, and y_2 is the synthetic futures price. The null hypothesis is that the synthetic futures price does not Granger-cause the Upper Midwest cash price. This is equivalent to a test of $A_{2j} = 0$ for j=1,...,n, and can be tested using the usual F-test (see Granger and Newbold). In practice, n is identified by estimating a statistical criterion at various lags where the optimum value is given when ϵ behaves as white noise. A complete discussion of causality tests is contained in Bishop. The results of Granger causality tests for milk prices are discussed in the main body of the paper.

Table B1. Results of Augmented Dickey-Fuller tests for unit roots for various milk prices in natural logs, January 1988 through April 1995.

Price Series	Estimated t- statistic	Critical Value 10% level of significance
Upper Midwest blend price	-3.1802	-2.57
California blend price	-2.2587	-2.57
BFP price	-3.488	-2.57
Synthetic futures price	-3.0584	-2.57

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