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Price Volatility and Structural Breaks In U.S. Dairy Markets

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Abstract

This paper examines whether price volatility has increased for the all-milk price and milk margin over the past 25 years. It focuses on the impact of exports and attempts to establish the existence of structural changes in the market. Various models are applied to analyze the stated question and results discussed. This paper finds that there was a distinct structural break in the milk price and possibly in the milk margin. Trade has a limited correlation to volatility in the milk margin and milk price.

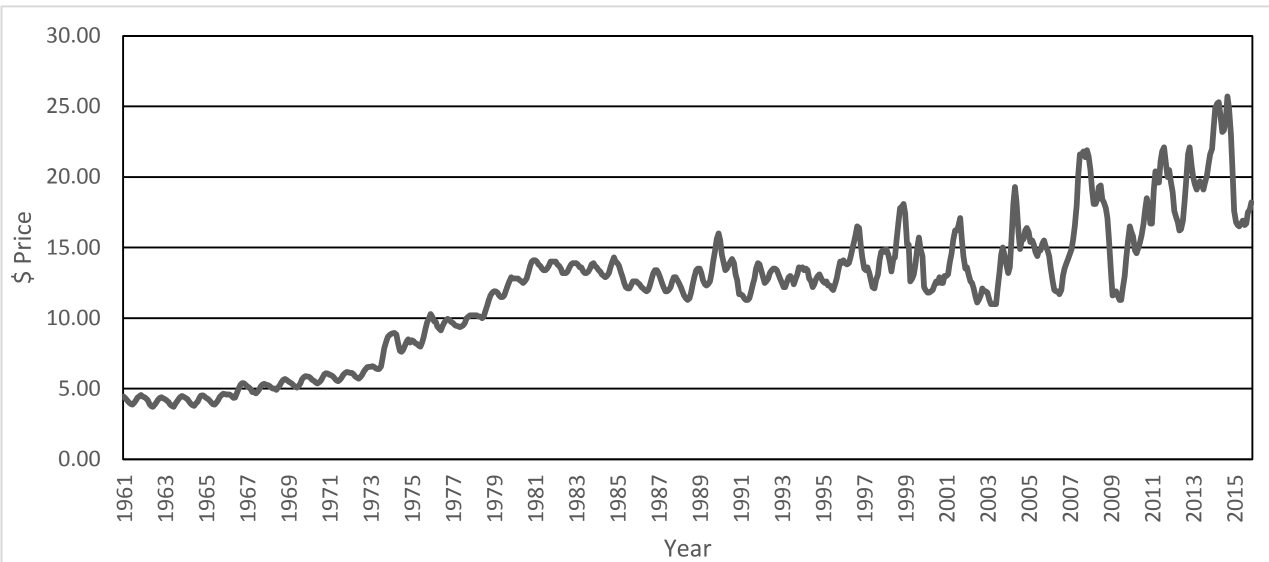
Introduction and Institutional Background

The 2014 Farm Bill, signed into law on February 7, 2014, authorized the replacement of the Milk Income Loss Contract (MILC) program with the new Margin Protection Program – Dairy (MPP – Dairy, or MPP for the purposes of this paper). The MPP went into effect in September of 2014 and will be effective through the end of 2018. It functions much as an insurance policy for dairy producers. The MPP is consistent with a long line of government price-support programs in the dairy sector designed to provide price stability and risk management for producers.

While producers tend to hold to the idea that there has been an increase in milk price and margin volatility, there is widespread disagreement on the subject of food-price volatility in agricultural commodity markets in academia, primarily dependent on the time frame considered. Many models show an increase in volatility due to ethanol markets, deregulation, and other causes (Braun & Tadesse, 2012) while other models show that most prices are actually less volatile than historical averages (Gilbert & Morgan, 2010). While there have been a number of studies on this general topic of food price volatility, there are few empirical studies specific to the producer side of the dairy industry, and even fewer focusing on the change in the milk price and margin volatility in more recent years. It is on this point that this research makes a contribution. I examine the milk market over the period of January 1989 to November 2015 and test whether the milk price and milk margin have become more volatile over this period. I also examine the possibility of structural breaks in the market focusing on the effects of the recently expanded export market for U.S. dairy products. These tests are largely be based on the stationarity of the milk price (i.e. does the series have a time-invariant variance?). There are three reasons for focusing on this time period. First, as will be examined later, prices were reasonably stable prior to this point. The second reason is due to the lack of continual, monthly trade data for the dairy sector prior to 1989; and, as the effect of trade is one of my primary examination objectives, I have chosen to focus on this time frame. The third reason for looking for structural changes since the late 80s, is due to existence of other research that sufficiently documents the change in the market prior to this point consistent with earlier policy changes (Dobson and Christ 2000).

While I will be focusing on milk prices from 1989 onward, it is interesting to note the history of the milk price since 1961. The all-milk price from January 1961 to November 2015 is shown below in Figure 1 (not adjusted for inflation).

(Fig 1) Monthly Milk Price



A visual observation shows that there is obviously an inconsistent variance and likely a time dependent mean over the past 55 years, and testing will show this; however, this research focuses on the possibility of a fundamental change to the stochastic process that determines market prices within the past 25 years.

The arguments that prices have become more volatile over the past 20 or 30 years comes at the end of a history of deregulation beginning in the 1980s when many price supports began to be phased out. The standard deviation in monthly farm milk prices for the 1990s was about double that in the 1980s (Nicholson and Fiddaman 2003).

The objective of this paper is to provide a simple, working model that demonstrates the existence or nonexistence of increased price volatility in the milk market and establish the presence of structural changes to the market by focusing on the effects of exchange rates and export markets, which are common topics addressed in legislation. A minor, secondary, objective is to present this model with its ramifications in such a way so as to be useful to the layman producer in long-term planning as the knowledge of changes in the markets is essential for proper risk management.

Data

The dataset collected consists of the monthly All-milk price from the USDA Agricultural Marketing Service between January 1989 and November 2015. During this time, the market saw drastic fluctuations from near record lows to record high prices. The all-milk price is a representative price taken by the average producer per 100 lbs. of milk, and is highly correlated with the Federal Milk Marketing Orders (FMMO) that regulate the vast majority of U.S. milk production. The next variable included is a composite of the input costs of corn grain, soybean meal, and alfalfa hay. The following formula is used by the USDA to calculate feed costs under the MPP and is designed to represent the feed cost of producing 100lbs of milk:

$$\text{Feed Cost} = (1.0728*\text{corn \$/bu}) + (0.00735*\text{soybean meal \$/ton}) + (0.137*\text{alfalfa \$/ton})$$

By taking this cost and subtracting it from the all-milk price, we obtain the dairy production margin (DPM) or milk margin:

$$\text{DPM} = \text{All-Milk price} - \text{Feed Cost}$$

This margin is used under the MPP to calculate payouts under the program, which is a reasonable representation of average margins remaining to pay labor, owners of capital, and other inputs. Actual margins will vary by region, but for the purposes of this paper it is sufficient as it is a reasonable average, and has been applied as a blanket covering all U.S. milk production under the MPP. All of the dollar values used in the models are adjusted for inflation using the CPI posted by the Bureau of Labor Statistics, which uses an average of the years 1982 to 1984 as its base level.

I have also included data for the U.S. production of dairy products. The first is the production of raw milk given in millions of pounds. The production value is calculated by multiplying production by the all-milk price. Trade data for imports and exports collected are based on the 4-digit code system compiled by the USDA for the Foreign Agricultural Trade of the U.S. (FATUS). The USDX, an index of the dollar’s value against a basket of foreign currencies, is included as the exchange rate in my analysis.

Prior research

There has been a fair amount disagreement on the topic of whether agricultural commodity price volatility has increased over the past couple of decades. Recent, anecdotal opinion tends to side with the fact that it has. I will present some of the past models and arguments made in various articles on both sides of this argument.

At the Agricultural and Applied Economics Association's Annual Meeting, August 12-14, 2012, in Seattle, Washington, and later published in the Journal of Energy Economics, Wang and McPhail (2014) examine the impacts of shocks to energy on agricultural productivity growth and price variation over the period 1948 to 2009. In addition to the effects of energy, they find that the global demand shock in U.S. agricultural exports is the major factor in explaining the volatility in U.S. food prices, accounting for one-third of the food price fluctuations.

In the Journal of Dairy Science, Bozic et al. (2012) examine the term structure of the milk margin by using the futures markets for milk and for feed commodities. They noted that the futures markets were good predictors of the time necessary for mean reversion in the margin, and that when margins are exceptionally high or low, the time required for the milk margin to revert to its mean will take comparatively longer (up to nine months). They also note that the futures markets are not good at predicting the occurrence of shocks to the margin or the timing of the start of margin recovery.

An article from the National Bureau of Economic Research concludes that the tie between biofuel demand and agricultural commodities has strengthened; and particularly when fuel prices are high, they have observed an increased price volatility in agricultural markets. While they do not specifically consider the dairy industry, the correlation between milk prices and feed stocks, which they do tie to energy volatility, is well established. (Hertel & Beckman, 2012).

The interdependence of food and biofuels is further examined by Ciaian & Kancs (2011) with a structural vector autoregression (VAR) model of nine agricultural prices and oil prices. They found that there were no cointegration relationships over the period 1994 to 1998; however, they found both corn and soybean prices to be cointegrated with crude oil prices for the period 1997 to 2003. All nine prices were found to be cointegrated with oil prices over the period 2004 to 2008.

Von Braun and Tadesse (2012) make the argument that not only has the trend of food prices been positive, but the frequency of price spikes and overall volatility has also increased. The models they applied are based primarily on finished products (including various dairy products) rather than the raw commodity prices, yet we would expect these to be very closely correlated. They attribute this to speculation in futures markets, extreme weather patterns, and biofuel demand, among other factors (Braun & Tadesse, 2012).

Dong et al. (2011) published a volatility model based on futures markets, concluding that the volatility of prices diminished following a consistent pattern as the contract approached maturity. In addition to this they found a degree of Granger causality in the corn futures markets.

In 2010, Gilbert and Morgan (2010) addressed the "widespread view that food price volatility has increased." They found, however, that volatility has been generally lower over the past two decades than historical averages. They do concede that some grain markets may be experiencing an increase in volatility, but state that more data will be required before a final conclusion may be reached.

Awokuse and Wang (2009) primarily discuss the asymmetries of price transmission in dairy markets and the volatility of the margin at various levels of the industry. They also touch on the concept of increased volatility in food prices citing a number of governmental inquiries into milk pricing irregularities.

Another model evaluating government intervention, with a particular focus on the price floors that were removed in the early 1990s, found that this led to an increase in price volatility. They found significantly more short-run price volatility, both in the dairy market as well as other related commodities, when the price floors were removed (Chavas & Kim, 2004).

Nicholson and Fiddaman (2003) presented their findings at a conference of the Systems Dynamics Society in New York in 2003. They applied dynamic modeling to the US dairy industry with the specific goal of looking at the effects of deregulation beginning in 1988. They also look at supply chain and demand shocks along with other industry changes, and conclude that the volatility of dairy prices has indeed increased over the decade studied.

There are many other articles along the same lines as the ones mentioned above. I have chosen to focus on those that are more contemporary as I intend to use data that is covering only the past 25 years. Many of these articles establish the tie between energy and commodity markets or between various commodities. It is my intent to examine the correlation between trade and milk price volatility using similar, time-series econometrics.

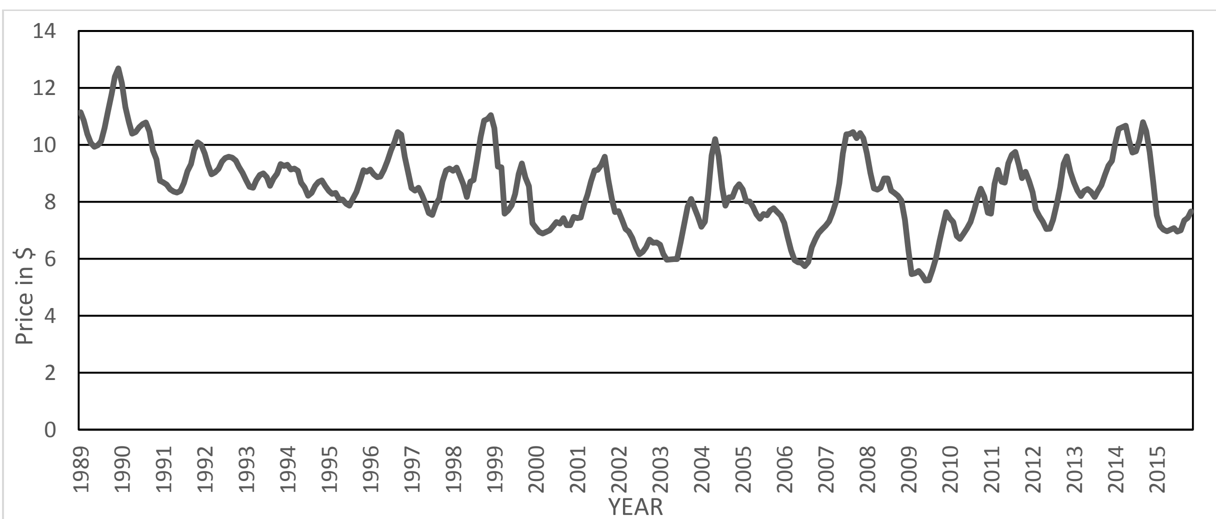
The Question of Stationarity

The stationarity of a stochastic process is an essential part of determining the existence of structural breaks. Using an Augmented Dicky Fuller (ADF) test, we test whether the milk price is trend stationary. The following equation is used for this test, where ΔP represents the change in variable P (milk price). Lower-case γ is the coefficient estimated to determine whether the series has a unit root where the number of lags of the change in price are determined by the AIC criterion (See Enders. p. 203).

$$\Delta \mathrm{P(t)} = \gamma P(t-1) + \sum_{j=1}^{p-1} \delta(j) \Delta P(t-j) + \varepsilon(\mathrm{t})$$

When we observe the inflation adjusted milk price data from 1989 to 2015 (Figure 2) there is a possible, negative trend. This could reflect either a trend-stationary process, or a random walk with a drift process. The latter of these contains a unit root.

(Fig 2) Price Levels



This trend can be taken into account by including a time trend, denoted βt, and a constant, α, in our equation (shown below) estimated by the ADF test.

$$\Delta \mathrm{P(t)} = \alpha + \beta \mathrm{t} + \gamma P(t-1) + \sum_{j=1}^{p-1} \delta(j) \Delta P(t-j) + \varepsilon(\mathrm{t})$$

Appling these tests to the milk price data, we obtain the following results. Without compensating for a trend or constant, the t-statistic for γ is -0.8188 (p-value of 0.3615), at which level we fail to reject the null hypothesis that there is a unit root. When we account for a non-zero mean, via our constant, α, the t-statistic becomes -4.225 (p-value of 3.32e-5), at which, we can reject the null hypothesis that there is a unit root. Accounting for the time trend and constant, we obtain a t-statistic of -4.460 (p-value of 4.7e-5) at which we can also reject the null hypothesis that there is a unit root at a 99% confidence interval. This indicates that the milk price from 1989 to 2015 is a trend-stationary process, meaning that it can be consistently modeled by an autoregressive (AR) model which accounts for a time trend and non-zero mean.

Our ADF test with a constant and time trend (lags determined by the AIC method) indicates that an AR model with three lags to be the best fit. In the following model, Price is the all-milk price, 'a' is a constant, (t-n) indicates an 'n' month lag and b1, b2, b3, and b4 are the coefficient values.

Price = a + b1(time trend) + b2(Price(t-1)) + b3(Price(t-2)) + b4(Price(t-3))

From this regression, we obtain the following results with an adjusted r-squared value of 0.9462:

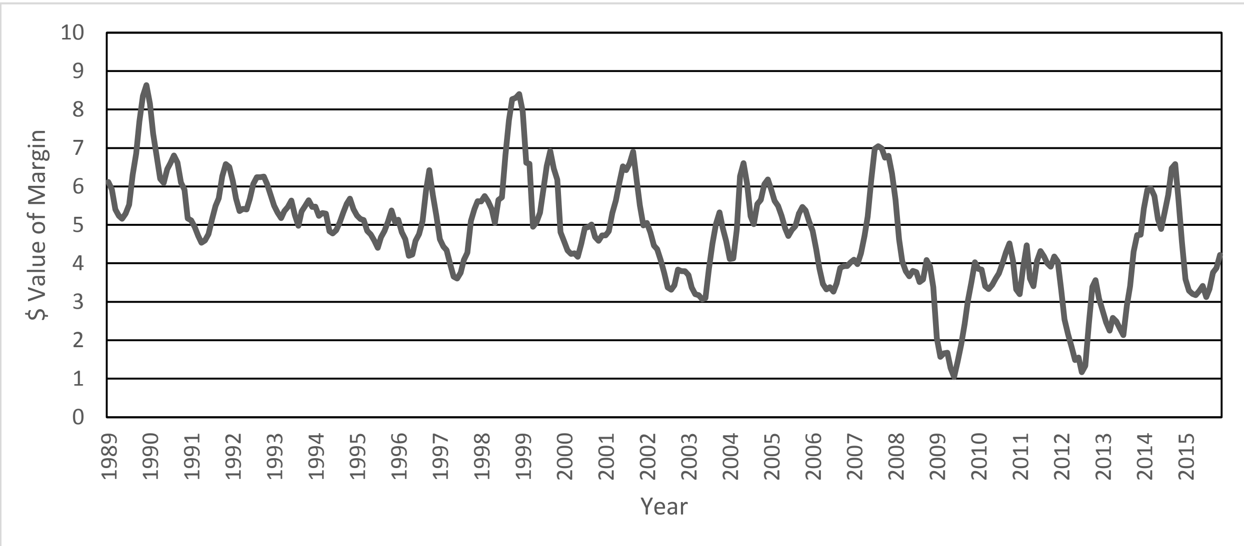
Price Dependent AR

Variable	**Coefficient**	**Std. Error**	**P-Value**
Constant	0.393876	0.15387	0.0109
Time Trend	-0.000208	0.00014	0.1552
Price t-1	1.97302	0.07439	3.7e-82
Price t-2	-1. 4226	0.13448	1.44e-22
Price t-3	0.406467	0.070	1.56e-8

The residuals are not normally distributed, and, upon testing for an autoregressive conditional heteroskedasticity (ARCH) effect, with a 12 lag order, we reject the null hypothesis that there is no ARCH effect with a p-value of 2.669e-8. This is a strong indication that there is indeed an inconsistent variance. Looking at the variance in segments of the data confirms the visual increase in variance which we observed earlier. It is more evident that that there has been an increase in the volatility of prices over time after looking at Figures 4 and 5, which will be discussed later on.

If we apply the same ADF tests to the milk margin (Figure 3), there are similar results. There is strong evidence to reject the unit root hypothesis including a constant and trend. When only a constant is included the null can still be rejected, just as with the price; however, there is not sufficient evidence to reject the null without a trend or constant. This indicates that the data is trend stationary.

(Fig 3) Margin Levels



The ADF test for the milk margin indicates that the best-fitting model includes a constant and three lags. From this model we obtain the following results with an adjusted r-squared value of 0.9386:

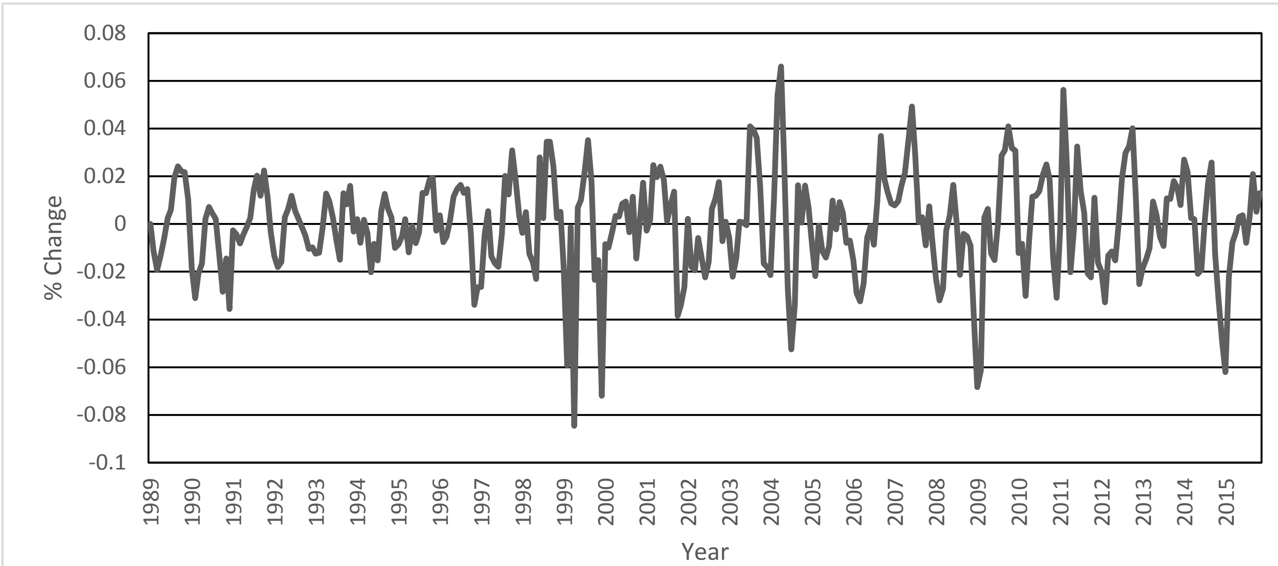
Margin Dependent AR

Variable	**Coefficient**	**Std. Error**	**P-Value**
Constant	0.4303	0.138019	0.002
Time Trend	-0.00059	0.000204	0.0041
Margin t-1	1.83446	0.096547	4.00e-54
Margin t-2	-1.20149	0.169883	9.93e-12
Margin t-3	0.296868	0.087108	0.0007

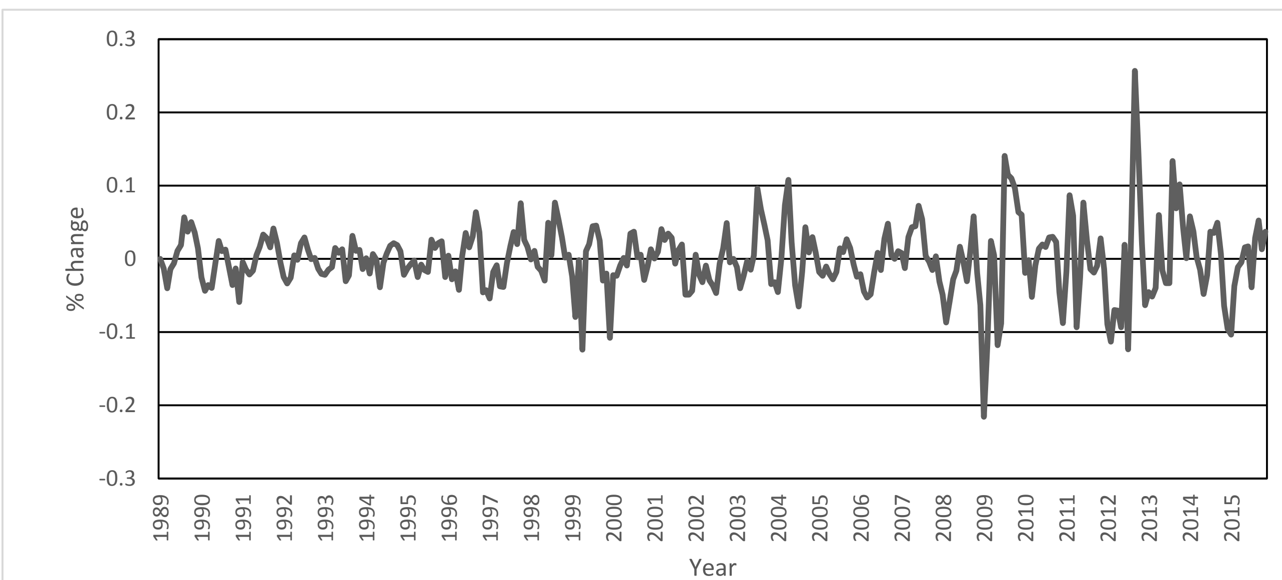
This model also has non-normal residuals, and has strong evidence of an ARCH affect (a p-value of 5.159e-9).

These results indicate that while the data is at least trend stationary, there exists the possibility of an inconstant variance, that is, the data is not covariance stationary. One possible way of dealing with this, is to transform the data by taking the log and first difference (i.e. percentage change). Figures 4 and 5 illustrate the time series plot of these two transformations, which I will use in other models to come.

(Fig 4) Logged First Difference of Milk Price



(fig 5) Logged First Difference of Milk Margin



An ADF test on both the percentage change in the milk price and the milk margin yield results that indicate they are both free of any unit root with or without a trend; however, when modeled, both show strong indications for heteroscedasticity indicating that both series are still not covariance stationary.

A visual examination of these two variables offers the possibility of a structural break at a couple different points in time. December of 1998 appears to be the most likely candidate for the price, while

December of 2008 appears to be a sharper break in the pattern of the margin. One possible explanation for the first of these changes could be due to the reduction of price supports in the mid to late 90's. The second visible change coincides with the time when the U.S. began to be a consistent, net exporter of dairy products, which we will examine later on.

Conducting an F-test to test for structural breaks can be done by first splitting the data at the point that appears to be our most likely location for the break. The equation below can then be applied where the F-value of the test is defined as the ratio of the variance before the split σ^2 (b) divided by the variance after the split σ^2 (a). We reject the null hypothesis that the variance between the two groups is the same if the F-value from the test is greater than the critical value from the F distribution (Rodionov 2005).

$$F = \frac{\sigma^2(b)}{\sigma^2(a)} \succ F(crit)$$

When we apply this test to the milk price, the F-value is 1.614. For a one-tailed test at a 95% confidence interval, the critical F-value is 1.317 indicating a strong likelihood for a structural break in the variance in the price in December of 1998. For the milk margin the critical F-value testing for a break in December of 2008 is 1.319, while our test value is 1.266. This gives us a p-value of .0807, at which we cannot reject the null hypothesis that the variance between the two data segments is different at the 5% level. Even so, it is an interesting point to consider for a break.

If we test for a structural break in the milk margin at 1998, we have an F-value of 2.081 and a critical value of 1.317, which indicates that there is a strong possibility of a structural break in both the milk price and in the milk margin in December 1998.

The next step in testing the structural break is to test each segment of the data for covariance stationarity much like we did at the beginning of this section. This means that we run an ADF test for a unit root in milk price for the data between January 1989 and December 1998. We then run a separate ADF test for the data from January 1999 and November 2015. The same method of testing is applied to the milk margin using data sets from 1989 to 2008, and from 2008 to 2015. The test for the margin will then be repeated using the same time sets as the milk price.

From the preliminary ADF tests on the milk price it was necessary to take the first difference of the log, to resolve the issue of a unit root. Based on the test on the logged difference of milk price we can specify an AR(2) model for the data before 1998 and an AR(1) model for the data thereafter. Both data sets have no unit root. When we test for an ARCH effect, there is a p-value of 0.6149 for the data prior to 1998 and a p-value of 0.5716 for the data after 1998. At these values we fail to reject the null that there is no ARCH effect present. The lack of a unit root and heteroskedasticity indicates a covariance stationary process if we allow for a structural break.

It was again necessary to take the first difference of the log to resolve the issue of a unit root for the milk margin. Our ADF tests indicate an AR(3) process for the margin prior to December 2008 and an AR(1) process thereafter. When Each of these models is tested for heteroskedasticity the results are mixed. For the later segment from 2009-2015, we obtain a p-value of 0.1925 indicating that there is not a significant ARCH effect. For the data before 2009, we obtain a p-value of 3.522e-7, at which level we can reject the null that there is no ARCH effect, which indicates the possibility of a structural break before that time.

If we split the milk margin data at December 1998, we have two series which show no unit root, and can be modeled by an AR(4) process before 1999, and an AR(1) process thereafter with AIC lags. With these models, we obtain a p-value of 0.1365 for the ARCH test for the series from 1989 to 1998, and a p-value of 0.0023 for the series from 1999 to 2015 meaning we can assume a significant amount of heteroscedasticity after 1998.

From this set of tests, we have a great deal of evidence for a single structural break in the pricing of milk in December of 1998. Segments of the milk margin can be shown to be a covariance stationary series depending on where we test for a break; however, there is no single, clear break. It is possible that there have been multiple changes in the milk margin volatility between 1998 and 2008 or that the variance in the milk margin increased slowly following the structural break in the price.

The Effect of Trade

To examine the effect of the exposure to international trade, and its possible effect on the variance we define the export ratio as the value of dairy products exported divided by total value of production, and the exchange rate as the value of the dollar as given by the USDX. Using the percentage change designated as ld_Margin and ld_Price for the milk margin and milk price respectively, we can modify the AR equations from above to the following:

$$ld\_Margin = a + b1[ld\_Margin(t-1)] + b2(Exchange\ Rate) + b3(Export\ Ratio)$$

This equation can be altered to fit an autoregressive estimation similar to those used to test each time segment of the milk margin and milk price above. By running this regression for each segment before and after the potential structural breaks we should be able to show the correlation between trade and volatility.

For all of the regressions run on the milk margin, the exchange rate and export ratio were statistically insignificant with the exception of the exchange rate before 1999, which had a p-value of 0.0066. Its positive correlation indicates the possibility of a high dollar value having a destabilizing effect on margin volatility, although this is not necessarily a causal relationship.

The story is similar when we look at the milk price. Post 1998, neither the exchange rate nor the export ratio prove significant; however, before 1999, the exchange rate yields a positive coefficient which is significant at the 5% level (a p-value of .0418). The Export ratio is still insignificant in this data segment.

An alternate regression, which uses the percentage change in the exchange rate and export ratio rather than the levels, gives us slightly different results. For the milk margin from 1989 to 1998 or from 1989 to 2008, the percentage change in both the export ratio and the exchange rate show no statistically significant correlation with volatility. For the series after 1998 and 2008, the export ratio is negatively correlated with volatility with a p-value of 0.0084 and 0.0376 respectively. The percentage change in the exchange rate is not significant in either, and has no effect when omitted. These results would indicate that exports could have a stabilizing effect on milk margin volatility.

When considering the milk price, the percentage change in the exchange rate is insignificant for both models on either side of 1998. Its omission also has no effect on the significance of other variables. Unlike in the model using the level of the export ratio, the percentage change in the export ratio has no significance prior to 1998, and is negatively correlated thereafter with a p-value of 0.00007, which again is in line with a possible stabilizing effect of exports on milk prices

Results Summary

Each of these models has tried to demonstrate whether there is increasing volatility and/or structural breaks in the milk price or milk margin. In the AR models for both price and margin, we see a strong ARCH effect, which follows with popular opinion of producers that there is an increased volatility in the market. The lack of a unit root in the data, however, indicates that the milk margin and milk price do not have a structural break in the mean if they are modeled accounting properly for trends. The heteroskedasticity evident in all of these models is the only remaining argument for a possible structural change in the market.

There is a statistically significant difference in the volatility in both the milk price and milk margin before and after 1998. In the milk margin there is a possible variance difference before and after 2008. In addition to this difference, when the data before and after these breaks is run in an independent regression, we observe covariant stationarity over the whole data set for the milk price. This is a strong indication that there has been a structural change in the market determining milk price.

The conclusion on a structural change in the milk margin is less clear. Individual series segments are covariance stationary; however, there is not a discrete break that allows us to model two, covariance stationary series. One of the two segments has persistent evidence of heteroskedasticity, which prevents the clear labeling of such a break as we saw in the milk price. It could be that the margin, which is tied to price by definition, adjusted slowly to the break in milk prices. The other possibility is that there have been multiple structural breaks in the milk margin between 1998 and 2008; however, we have no theoretical reason to expect this, when there is no such evidence in the milk price.

In examining the objective to determine the effect of export markets on volatility, the results are predominantly negative. There is some evidence of the exchange rate being positively correlated to the volatility of the milk price and volatility of the milk margin in the segments before possible structural breaks in models using levels. The export ratio showed no effect in any of the level models, leaving significant room to argue that opening to trade has had no noticeable effect on the volatility of dairy markets in the U.S.

When the log differences were considered, we see no significance of the exchange rate in any model. We do observe a negative correlation between the export ratio and volatility of the milk margin and milk price, for the series after possible structural breaks. This indicates that there is a possible stabilizing effect on milk prices and the milk margin when proportionally more milk is exported.

Conclusion

To briefly restate the goals of this paper, its objective was to:

a. Empirically test for increased volatility in the milk price and milk margin

b. Test for the possibility of structural breaks in the milk market

c. Examine the role that exports and exchange rates play in this volatility

The raw data suggests an increase in milk price volatility or milk margin volatility over the period 1989 to 2015; however, there is no evidence of a unit root when the model is properly specified. The absence of a unit root in the first difference of the log, which indicates stationarity nullifies the possibility that there has been an observable structural break in the mean of either of the examined variables when trends are properly accounted for. It does not preclude the incidence of increased volatility, which we do observe. The volatility of milk prices has increased significantly from pre 1998 to post 1998. When tested for a structural break there is strong evidence that there is a fundamental change in the market at this point. The milk margin shows distinct possibilities for a structural change in December of 1998 and in December of 2008.

Taking trade into account, there seems to be a limited correlation between exports, exchange rates and the volatility of milk prices or the milk margin. There is not sufficient evidence to reach a strong conclusion on this matter, and further research would be required; however, preliminary findings indicate that the exposure to export margins tend to have a stabilizing effect on milk price and milk margin volatility, which has increased in spite of this effect. This runs contrary to common opinion that opening up to trade exposes producers to higher levels of risk due to increased volatility. There is still a lot of room for further research in this area.

The results presented in this paper argue the point that there has been an increase in milk price and margin volatility over the past 25 years; however, this does not seem to correlate extensively with the growing export market. There is statistical evidence that there has been a structural change in the milk price at the end of 1998, and there is a possibility of a structural change to the milk margin in between 1998 and 2008.

These implications for those involved in milk production in the U.S. are significant. The dairyman who has started out in the past 15 years is dealing with a market fundamentally different than it was for his predecessors (whom he was likely mentored by). He will be required to plan accordingly for more price and margin volatility, and uncertain regulations. Risk management could foreseeably push more volume through a presently small futures market, or we may see the further expansion of large cooperatives and vertical integration changing the structure of how we move milk from the farm to the table. One thing is for certain; the industry that most dairymen built their businesses in is not what it once was.

Like all economic questions the best answer is always, “on the other hand, it depends.” I would argue that the dairy industry has fundamentally changed, and that we will continue to see it evolve to deal with its environment. There are obviously more things going on under the surface than these simple models can explain, and there is room for further research on countless topics merely touched upon here. In the end, the market has changed, but the reason is still up for debate.

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