Journal of Agribusiness 37, 1 (Spring 2019)

Impact of Alfalfa Exports Surge on Dairy and Feed Markets in California

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Alfalfa hay exports have surged considerably since 2009, with 95% of shipments being supplied from seven western states. Many of these states are major U.S. dairy and alfalfa hay producers; California is the nation's largest producer of both commodities. We investigate these alfalfa exports from the year 2000 until present, seeking to determine if the spike in their dynamic evolution has resulted in a structural break, and find significant evidence of this for the year 2009. Just as important, we investigate whether there has been a change in the dynamic long-run relationships between California dairy and alfalfa markets for the periods' pre- and post-break of alfalfa exports. We identify significant differences among these two periods; specifically, the long-run equilibrium between milk and alfalfa hay prices and its speed of adjustment following a shock to either market. Results have implications for risk management and policy analysis.

Key words: Alfalfa Exports, California Dairy and Alfalfa Markets, Structural Break, Reference Price, Co-integration

Alfalfa hay exports have been growing steadily especially from the beginning of 2002 (Figure 1). These alfalfa exports originate mainly from western states. The initial alfalfa hay export uptick occurs in 2002, though it is more prominent after 2009 (dotted line in Figure 1 indicates February 2009). Putnam, Matthews, and Sumner (2013) noted that 99% of alfalfa exports are shipped from western ports. Putnam, Matthews, and Sumner (2015) also noted that "…more than 95% of these exports originate from the seven western states of Arizona, California, Idaho, Nevada, Oregon, Utah and Washington," and, in particular, California and Idaho are the two largest alfalfa-producing states in the United States (U.S. Department of Agriculture (USDA) National Agriculture Statistics Service (NASS), 2018). The seven western states produced just over 33% of total U.S. milk production in 2017 (U.S. Dairy Statistics, 2017). As a result, this increase in alfalfa hay export operations opens a new, growing market for alfalfa hay producers, having an unexplored effect on the "pricing process" in alfalfa hay and its relationship with the milk markets in the West, in particular California.

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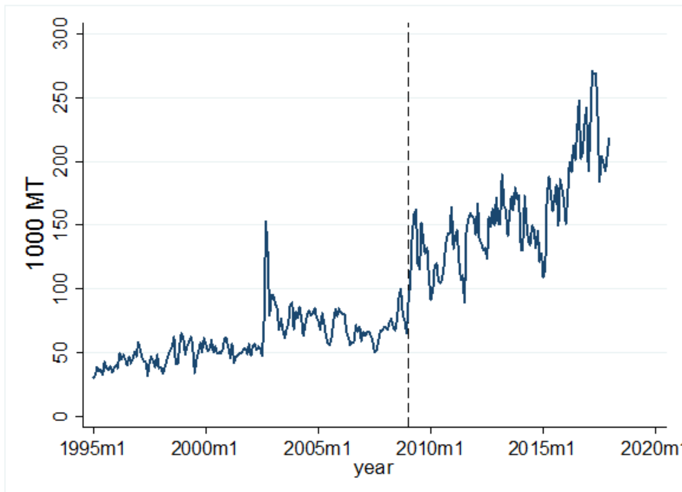


Source: USDA FAS.

Note: Seven Western states are Arizona, California, Idaho, Nevada, Oregon, Utah, and Washington; dotted line indicates the potential structural break in alfalfa hay export in February 2009.

Figure 1. Monthly Alfalfa Hay Export from Seven Western States.

Alfalfa hay is a main feed component for the dairy industry and the concentration and scale of dairy producers varies considerably by state. In the case of California, 75-85% of alfalfa hay production was consumed by the dairy sector that includes milk cows, heifers, and dry cows (Klonsky, Reed, and Putnam, 2007). As a result, alfalfa hay production is closely linked with the dairy production system, and dairy and alfalfa hay markets are inter-connected. Unlike other major feed components such as corn and soybean meal, alfalfa hay markets do not have a presence in the futures markets. The lack of a futures market plays a critical role in providing information for the commodity markets' price discovery process (Leuthold, Jankus, and Cordier, 1989). Price discovery is about determining which market is more informative for fundamental valuation when similar commodities or inter-connected commodities like alfalfa hay and milk are traded in different markets. A number of different methods have been used to study price discovery. One of these methods is to use bivariate time series analysis with the error correction term and compare the speed of adjustment between the two series (Gonzalo and Granger, 1995). We make use of this method to identify the dynamic interrelationship between California milk and alfalfa prices. A detailed description of these methods is presented in the following sections.

This study determines the dynamic relationships between alfalfa hay and milk markets in California. In particular, the study identifies whether these markets underwent significant (structural) changes following a surge of alfalfa hay exports in 2009 to China. In effect, since 2009, alfalfa shipments to China grew roughly 800%, reaching about 575,000 metric tons in 2013 (Pierson, 2014), and continued its growth to 1.4 million metric tons in 2016 (Matthews and Sumner, 2017). More importantly, this paper determines possible implications from the impact of these growing alfalfa hay exports on the interrelationship between the California alfalfa and dairy markets. We identify changes in the dynamic price process among these two markets, and also in the long-run equilibrium between the two prices, by applying a price discovery framework. California is both the country's largest dairy producer and alfalfa producer and exporter, with its industries valued at about $6.07 billion (milk production, 2017 State Ag Report) and $797 million (value of hay and haylage production, 2017 State Ag Report), respectively. Results of this study provide insightful information to risk managers as well as policymakers in the alfalfa hay and milk industry in California, in addition to the surrounding western state alfalfa exporting markets.[1]

To the authors' best knowledge, no previous studies have investigated the interrelationship between alfalfa hay and milk markets even though there have been numerous studies addressing price discovery across various commodities. Regarding alfalfa hay, Tejeda, Kim, and Feuz (2015) investigated the dynamic price relationships among alfalfa markets in seven western states including California. They concluded that California has a dominant effect on price movements of the other alfalfa hay-producing regions. We proceed by describing the data and methodology applied. We then present the results followed by discussion and implications. We conclude with final remarks and future lines of study.

Data and Methodology

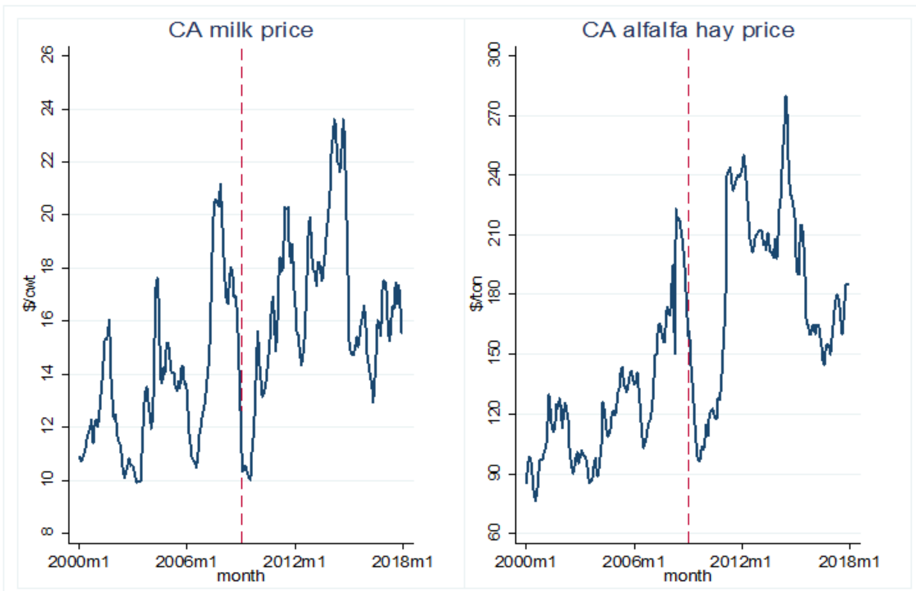
Monthly alfalfa hay export volumes from January 1995 to December 2017 are tested for structural break(s) using a dynamic programming approach from the Bai-Perron test (1998, 2003). The Bai-Perron (1998, 2003) test detects unknown break points (number of breaks and time of breaks). Let y_t be a series of data, for example, alfalfa hay export over time, and the equation $y_t = \beta_i + \varepsilon_t$ is estimated using sub-samples such that $t = T_{i-1} + 1, \cdots, T_i$ for $i = 1, \cdots, m+1$, where m is the unknown number of breaks. The coefficients $\hat{\boldsymbol{\beta}} = (\hat{\beta}_1, \cdots, \hat{\beta}_{m+1})$ are estimated by minimizing the sum of squared residuals (SSR);

$$\text{(1)} \qquad \min \quad SSR = \sum_{i=1}^{m+1} \sum_{t=T_{i-1}+1}^{T_i} [y_t - \beta_i]^2$$

for the m partitions of sample, i.e., $\hat{\mathbf{T}} = (\hat{T}_1, \cdots, \hat{T}_m)$. The second part of equation (1) is

[1] California recently accepted to change from its own Milk Marketing Order system that determines its milk prices to a Federal Milk Marketing Order system.

simply least squares to estimate β_i, and the Bai-Perron test finds $\widehat{\boldsymbol{\beta}}$ and $\widehat{\mathbf{T}}$ to minimize SSR in equation (1). We anticipate structural break(s) in milk and alfalfa hay markets as well for a similar moment in time, for example, year 2009.



Source: USDA NASS.

Note: Dotted lines indicate the potential structural break in both markets in February 2009.

Figure 2. Monthly California Milk and Alfalfa Hay Prices.

Subsequently, Vector Error Correction Models (VECM) are estimated with logarithmic values of California monthly price series of alfalfa and milk (documented by USDA NASS) from January 2000 to December 2017 (216 observations), taking into consideration the periods of pre- and post-break. That is, two VECMs are estimated considering the period prior to and the period after a structural break. Figure 2 presents monthly California milk and alfalfa hay prices. Unit root tests are applied by using Phillips-Perron (Phillips and Perron, 1988) and KPSS (Kwiatkowski et al., 1992) tests. In addition, the Johansen (1991) co-integration test is used to verify the existence of co-integration or a long-run relationship between two markets.

Price discovery covers identical, similar, or inter-related commodities that are traded in different markets, where a co-integration framework is typically adopted. The conventional price discovery approach used in the literature compares the speed of adjustment coefficients (as a share of the total adjustment) in a bivariate VECM. As explained by Arnade and Hoffman (2015), estimates of (absolute) adjustment rates are associated with market efficiency. The long-run equilibrium between alfalfa hay and milk prices can be written as follows:

$$(2) \qquad p_{milk,t} = \beta_{alf} p_{alf,t} + c + u_t \;\; \Leftrightarrow \;\; u_t = p_{milk,t} - \beta_{alf} p_{alf,t} - c$$

where $p_{milk,t}$ and $p_{alf,t}$ represent milk and alfalfa hay prices at time t, respectively. β_{alf} is the co-integrating parameter.

The term c (constant term) in equation (2) accounts for differences in these two markets. The term u_t is the (long-run) error, which equals zero in equilibrium.

The bivariate VECM contains this long-run equilibrium in equation (2) as follows:

$$(3) \qquad \Delta p_{i,t} = \alpha_i (p_{milk,t} - \beta_{alf} p_{alf,t} - c) + \sum_{l=1}^{L} \sum_{j=1}^{2} \gamma_{i,j,l} \Delta p_{j,t-l} + \sum_{m=1}^{11} b_m x_{m,t} + \varepsilon_{i,t}$$

where i = milk and alfalfa hay, β_{alf} is the co-integrating parameter, α_i are the "speed of adjustment" parameters, and $p_{milk,t} - \beta_{alf} p_{alf,t} - c$ is the price difference of alfalfa hay and of milk for month t (the long-run equilibrium). The coefficients α_{milk} and α_{alf} in the VECM determine the adjustment effect that a shock to one of the variables has on the system (Theissen, 2002). In long-run equilibrium, $p_{milk,t} - \beta_{alf} p_{alf,t} - c$ is zero. However, if p_{milk} or p_{alf}, or both deviate from the long-run equilibrium, this expression will be nonzero and each variable adjusts to partially restore the equilibrium relation. The α_{milk} and α_{alf} coefficients measure the speed of adjustment in the movement of the endogenous variables of milk and alfalfa towards the equilibrium. A value of $\alpha \approx 0$ would imply that, after a shock occurred, there would be a very slow adjustment back to a long-run equilibrium, which may imply severe market frictions. The parameters b_m are the coefficients for monthly dummies as shown in Figure 2, where monthly seasonality exists.

We investigate the reference price between milk and alfalfa markets, prior to and after the (potential) structural break, identifying whether there have been substantial changes in this dynamic process. To determine the reference market (price discovery), we calculate the relative ratio of the speed of adjustment coefficients in a manner similar to Schwarz and Szakmay (1994), Foster (1996), and Theissen (2002). Other measures of price discovery used in the literature are the Information Share (IS) of Hasbrouck (1995); and the Component Share (CS) of Booth, So, and Tse (1999); Chu, Hsieh and Tse (1999); and Harris, McInish, and Wood (2002). The IS measures each market's relative contribution to the variance of the efficient price, while the CS decomposes the common efficient price into a weighted average of observed market prices (similar to relative ratio of the speed of adjustment), and measures each market's contribution to the common efficient price. Both IS and CS are based on the reduced-form “forecasting errors” in a VECM (Kim, 2011). Following Schwarz and Szakmay (1994), the coefficients of the relative ratio of speed of adjustment θ_i are a function of the speed of adjustment parameters α_i:

$$(4) \qquad \theta_{milk} = \frac{|\alpha_{alf}|}{|\alpha_{milk}| + |\alpha_{alf}|}, \;\; \theta_{alf} = \frac{|\alpha_{milk}|}{|\alpha_{milk}| + |\alpha_{alf}|}, \;\; \text{and } \theta_{milk} + \theta_{alf} = 1$$

where a high (low) θ_i $(i = milk, alf)$ indicates a low (high) α_i which, in turn, implies that market i slowly (quickly) responds to an unpredicted shock in the system; therefore, market i is (not) the price discovery reference market. If $\theta_{milk} = \theta_{alf} = 0.5$, both markets contribute rather equally to the price discovery process; i.e. both markets move at a roughly similar pace toward the long-run equilibrium. We examine and contrast results obtained for the two periods estimated.

Results

The structural break test (Bai and Perron, 1998, 2003) identified February 2009 as a structural break point in alfalfa hay exports (Table 1), and we proceeded to partition the monthly price series accordingly, i.e. Pre-2009 (2000 M1-2008 M12, 108 observations) and Post-2009 (2009 M1-2017 M12, 108 observations). As shown in Table 1, regardless of the number of initially detected breakpoints, February 2009 persists as the date in alfalfa hay exports where a break occurred. Note that SSR in the Bai-Perron test was minimized with four structural breaks as shown in Table 1—April 1998, July 2002, February 2009, and May 2014. Also note that potential break dates for individual alfalfa, hay, and milk prices are slightly different from the break date identified for alfalfa hay exports. The Bai-Perron (1998, 2003) test suggested early 2011 as a break date in alfalfa hay price and early 2007 for milk price. Since our objective is to determine the effect from a surge on alfalfa exports on the dynamic relationship between the two (California alfalfa and milk) markets, we partition our series in accordance with the structural break found in alfalfa exports. In addition, at this time, we are not able to compare the statistical power of the break point tests performed among each of the series.

Table 1. Bai-Perron Structural Break Test Results for Alfalfa Hay Exports.

Breaking Points						SSR[1]
m = 1				2009 (Feb)		229,867
m = 2				2009 (Jan)	2014 (May)	173,690
m = 3		2002 (Jul)		2009 (Feb)	2014 (May)	134,592
m = 4	1998 (Apr)	2002 (Jul)		2009 (Feb)	2014 (May)	128,863*
m = 5	1998 (Apr)	2001 (Dec)	2005 (Jul)	2009 (Feb)	2014 (May)	131,651

*[1] Sum of squared residuals in Bai-Perron test. *Indicates the minimum value of SSR, that is, there might be four structural breaks in alfalfa hay export.*

Unit root tests are performed on each price series (Table 2) for pre- and post-2009 periods. In both these periods, milk and alfalfa hay prices are determined to be non-stationary, as shown in Table 2. Note that the Phillips-Perron test in Table 2 is testing the null hypothesis of nonstationarity, thus the series is stationary by rejecting the null hypothesis. Conversely, the KPSS test is testing the null hypothesis of stationarity, thus the series is stationary by failing to reject the null hypothesis.

We then apply Schwarz criteria to estimate the number of optimal lags in the VAR models considering monthly dummies, and find the optimal lag length for the respective estimated period's VECM (Enders, 2004; pg. 358). Results from this are of estimated VECM (1) models with monthly dummies, for both periods. The Johansen test for co-integration (Johansen, 1991) results in one long-run relationship between milk and alfalfa prices, in each period at 10% significance level (Table 3).

Table 2. Unit Root Tests.

	All (N = 216)		**Pre-2009 (N = 108)**		**Post-2009 (N = 108)**	
Raw data	Phillips-Perron (non-zero mean)[b]					
	Milk	Alfalfa	Milk	Alfalfa	Milk	Alfalfa
Z(t) statistics	-2.809	-2.132	-2.145	-1.496	-2.128	-1.629
Lags[a]	4	4	4	4	4	4
5% critical value	-2.882	-2.882	-2.89	-2.89	-2.889	-2.889
Decision[c]	NS	NS	NS	NS	NS	NS
	KPSS test (level stationarity)[b]					
	Milk	Alfalfa	Milk	Alfalfa	Milk	Alfalfa
Test statistics	1.866	2.716	0.875	1.514	0.552	0.543
Lags[a]	4	4	4	4	4	4
5% critical value	0.463	0.463	0.463	0.463	0.463	0.463
Decision	NS	NS	NS	NS	NS	NS

[a] Lags for test is given by Newey-West lags, int{4(T/100) $^{2/9}$ }, where T is the number of observations. b Phillips-Perron test - testing the null hypothesis of nonstationarity, thus the series is stationary by rejecting null hypothesis. KPSS test - testing the null hypothesis of stationarity, thus the series is stationary by failing to reject null hypothesis. c Decision: NS = nonstationary, S = stationary.

Table 3. Trace Test on Order of Co-integration.

Pre-2009	included lags (levels): 2[a]			
Rank	Trace[*b]	p-value	Trace[c]	p-value
r = 0	19.44	0.0634	24.97	0.0628
r ≤ 1	5.06	0.287	10.51	0.107
Post-2009	included lags (levels): 2[a]			
Rank	Trace[*b]	p-value	Trace[c]	p-value
r = 0	28.99	0.001	28.88	0.018
r ≤ 1	4.37	0.371	4.35	0.693

[a] *Optimal number of lags is determined by minimizing Schwarz Criterion. b Trace* and C refer to the values of trace statistic with a constant. c Trace and C refer to the values of trace statistic with a time trend and a constant decision: The first "fail to reject" the null hypothesis occurs for r ≤ 1 (at 10%). Thus, there is 1 cointegrating vector in each sub-period.*

Upon modeling pre- and post-2009 VECMs, a ratio of speed adjustment $\theta_{milk} = 0.660$ and $\theta_{alf} = 0.340$ are obtained with α_i coefficients from VECMs (Table 4) for pre-2009 and $\theta_{milk} = 0.465$ and $\theta_{alf} = 0.535$ for post-2009. Therefore, we can infer that prior to the alfalfa export structural break that occurred in February 2009, the long-run relationship between California milk and alfalfa hay—following shocks to both or either market—responded quite asymmetrically in its adjustment speed when returning to their long-term equilibrium. In other words, when the California milk market was subject to an external positive shock (higher milk price), most of the adjustments in the long-run relationship between the milk and alfalfa prices occurred in the alfalfa hay market. This is inferred from the alfalfa market returning to long-run equilibrium at a much quicker pace. This, however, is not the case after 2009 where the speed of adjustment coefficient for milk became larger than before, specifically $\theta_{milk} = 0.465$ and $\theta_{alf} = 0.535$. These new coefficients imply that, after a shock to either market, the milk market will return to the long-run equilibrium at a quicker pace than prior to 2009 and, as a result, both markets return to the long-run equilibrium at a somewhat similar tempo.

The long-run equilibrium experienced a smaller change but that change is statistically significant. The slope parameter, β_{alf}, in the long-run equation $p_{milk,t} = \beta_{alf} p_{alf,t} + c$, is estimated to be $\beta^{pre} = 0.429$ (s.e.: 0.13) and $\beta^{post} = 0.493$ (s.e.: 0.08). Both estimates are statistically different, which implies that the impact of alfalfa hay in the long run has now increased. Figure 3 illustrates these results.

Table 4. VECM(1) Estimation Results.

Pre-2009

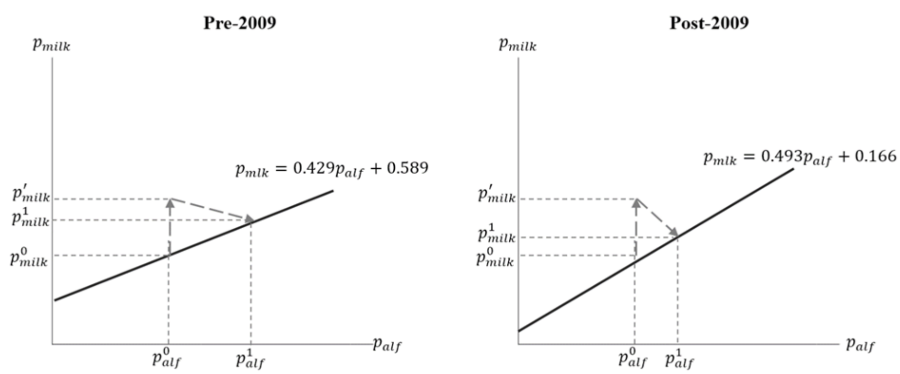
$$\begin{bmatrix}\Delta p_{1,t}\\ \Delta p_{2,t}\end{bmatrix} = \begin{bmatrix}-0.066^{*}\\ 0.128^{**}\end{bmatrix}\left[\begin{bmatrix}1, & -0.429^{***}\end{bmatrix}\begin{bmatrix}p_{1,t-1}\\ p_{2,t-1}\end{bmatrix} - 0.589\right] + \begin{bmatrix}0.590^{***} & -0.019\\ 0.401^{***} & -0.295^{***}\end{bmatrix}\begin{bmatrix}\Delta p_{1,t-1}\\ \Delta p_{2,t-1}\end{bmatrix} + \text{Seasonal Terms}$$

Pre-2009

$$\begin{bmatrix}\Delta p_{1,t}\\ \Delta p_{2,t}\end{bmatrix} = \begin{bmatrix}-0.146^{***}\\ 0.127^{***}\end{bmatrix}\left[\begin{bmatrix}1, & -0.493^{***}\end{bmatrix}\begin{bmatrix}p_{1,t-1}\\ p_{2,t-1}\end{bmatrix} - 0.166\right] + \begin{bmatrix}0.505^{***} & 0.106\\ 0.245^{***} & 0.260^{***}\end{bmatrix}\begin{bmatrix}\Delta p_{1,t-1}\\ \Delta p_{2,t-1}\end{bmatrix} + \text{Seasonal Terms}$$

*p < 10%; **p < 5%; ***p < 1%

We examine more closely the changes in the pre- and post-2009 slope (β) of the long-run equilibrium equations. In the pre-2009 period, the milk price increased by about 4.3% ($0.71/hundredweight (cwt) change) when the alfalfa hay price increased by 10% (roughly $17/ton change). In the post-2009 period, however, the milk price increased by 4.9% ($0.81/cwt change) when the alfalfa hay price increased by 10%, thus inferring that the impact of alfalfa hay on milk prices slightly increased after the structural break, by about 10 cents/cwt.



Note: Prices are in logs.

Figure 3. Illustration of Long-run Equilibrium and Speed of Adjustments.

The different speeds of adjustment, at the short run, have more interesting implications. Suppose that the milk price initially rises from p^0_{milk} to p'_{milk} after an unexpected shock to the milk market as shown in Figure 3. For the pre-2009 period, both milk and alfalfa hay markets respond to this milk market shock, but the alfalfa hay market is more responsive. The milk price decreases to p^1_{milk} (but higher than p^0_{milk}) and the alfalfa hay price increases to p^1_{alf}. The relative price adjustments in the milk market are substantially smaller than the price change in the alfalfa hay market. In the post-2009 period, however, the milk market would respond much more to the initial rise in milk price. That is, after the initial milk price increases from the unexpected shock to the milk market, the adjusting milk price decreases distinctively more for this post-2009 period than during the pre-2009 period (Post-2009 panel, Figure 3).

Policy and Management Implications

The structural change has likely increased the variability in returns for California dairy producers but may not have impacted the level of those returns. For example, if a shock brings about lower milk prices, alfalfa prices will be slower to adjust downward after the structural change, resulting in lower returns during that slower adjustment period. Conversely, a shock in the milk market that increases milk prices will also result in a slower upward adjustment in California alfalfa hay prices. As a result, returns will be higher for dairy producers during this slower adjustment period. These results should be of great interest to those selling dairy margin protection insurance and to producers who may be looking to insure or offset some of their added risk to their margins.

In effect, potential increases in return variability for dairy producers substantially augments the benefit of using risk management tools that properly consider this new dairy/alfalfa relationship. Dairy producers cognizant of the new scenario of added risk in their business who seek to protect their dairy margin may use insurance programs that specifically take into account the cost of alfalfa and obtain improved risk coverage of their returns over the use of other insurance programs that do not consider the prices of alfalfa. In particular, the dairy margin protection program—which covers the alfalfa market as part of its feed component—becomes an appealing insurance instrument.

Alfalfa continues to steadily increase its export trade volume and yet dairy has also been expanding its exports abroad. Exports of total milk solids have grown from about 1 billion pounds in 2003 to 4 billion pounds in 2017. (U.S. Dairy Export Council (USDEC), 2018). Mexico is, by far, the main destination for U.S. dairy products ($1.35 billion dollars, USDEC, 2018) followed by three very close (revenue-wise) markets—Canada, Southeast Asia, and China (each $700 million, USDEC, 2018). Thus the new dairy/alfalfa relationship, which is a result of the increasing alfalfa exports in conjunction with the increasing dairy export volume, is supported with trade policies such as the new, to-be-ratified-by-Congress United States–Mexico–Canada Agreement (the ex-North American Free Trade Agreement).

Conclusions

This study investigates the dynamic relationships between alfalfa hay and milk markets in California. In particular, the study determines whether these markets underwent structural changes following a surge in alfalfa hay exports; and, more importantly, it identifies possible implications from the effect of these growing alfalfa hay exports on the dynamic interrelationship between the alfalfa and milk markets in California.

The spike in alfalfa hay exports beginning in 2009 has resulted in a new, long-run relationship between California milk and alfalfa prices in comparison to the era prior to 2009, as shown in Figure 3. A main finding of this new relationship is that, following an external shock, the speed of adjustment towards long-run equilibrium is now relatively similar among the two markets. This result is substantially different from the previous period (pre -2009) where alfalfa prices were the major adjuster following a price shock among alfalfa and milk markets. A plausible explanation for this new, dynamic relationship is that alfalfa in California has experienced a much larger export market than before, resulting in a smaller effect on its market from changes in milk prices.

In addition, the structural change from 2009 is anticipated to raise the variability of California dairy producers' returns or margins, though not necessarily the level of those returns. Thus, the rise in the variability of margins should lead dairy producers who seek to offset this added return risk to be more attentive and interested in insurance programs that address margin (revenue minus feed) protection, and that specifically include the prices of alfalfa in feed calculations. In addition, this new relationship between alfalfa and milk prices in California is a result of increasing exports of alfalfa but also of dairy; therefore, policies addressing exports should be reaffirmed and further explored.

A limitation of the present study is the very recent agreement to incorporate California milk production into the Federal Milk Marketing Order system, which may influence future milk prices. This, in turn may, modify a bit the newly found relationship between alfalfa and milk prices. It is anticipated that this should not significantly change the implications of the results obtained here; however, it is valid to revisit the alfalfa hay/milk price relationship in several years. Additional factors to be considered are the effect from possible different feed components such as corn silage, as well as the effect of new policies and technologies being implemented. These are relevant matters for future study.

References

Arnade, C., and L. Hoffman. (2015). "The Impact of Price Variability on Cash/Futures Market Relationships: Implications for Market Efficiency and Price Discovery." *Journal of Agricultural and Applied Economics* 47:539-559.

Bai, J.. and P. Perron. (1998). "Estimating and Testing Linear Models with Multiple Structural Changes." *Econometrica* 66(1):47-78.

Bai, J.. and P. Perron. (2003). "Computation and analysis of multiple structural change models." *Journal of Applied Econometrics* 18:1-18.

Booth, T., R. So, and Y. Tse. (1999). "Price Discovery in the German Equity Index Derivatives." *Journal of Futures Markets* 19(6): 619-643.

California Department of Food and Agriculture, 2017 Report. Available at: https://www.cdfa.ca.gov/Statistics/PDFs/2016-17AgReport.pdf

Chu, Q., W. Hsieh, and Y. Tse. (1999). "Price Discovery on the S&P 500 Index Markets: An Analysis of Spot Index, Index Futures, and SPDRs." *International Review of Financial Analysis* 8(1):21-34.

Enders, W. (2004). *Applied Econometric Time Series*. 2nd ed. John Wiley Sons, Inc., New York, NY.

Foster, A.J. (1996). "Price Discovery in Oil Markets: a Time Varying Analysis of the 1990-1991 Gulf Conflict." *Energy Economics* 18:231-246.

Gonzalo, J. and C. W. Granger. (1995). "Estimation of common long-memory components in cointegrated systems. *Journal of Business and Economic Statistics* 13: 27-35

Harris F., T.H. McInish, and R.A. Wood. (2002). "Security Price Adjustments across Exchanges: An Investigation of Common Factor Components of Dow Stocks." *Journal of Financial Markets* 5(3):277-308.

Hasbrouck, J. (1995). "One Security, Many Markets: Determining the Contribution to Price Discovery." *Journal of Finance* 50:277-308.

Johansen, S. (1991). "Estimation and Hypothesis Testing of Cointegration Vectors in Gaussian Vector Autoregressive Models." *Econometrica* 59:1551-1580.

Kim, C-H. (2011). Essays on Price Discovery, Dissertation, Department of Economics, University of Washington.

Klonsky, K., B. Reed, and D.H. Putnam. (2007). "Alfalfa Marketing and Economics." In Summers, C.G., and D.H. Putnam eds. 2007. *Irrigated Alfalfa Management for Mediterranean and Desert Zones*. University of California Agriculture and Natural Resources Publication 8309.

Kwiatkowski, D., P.C.B. Phillips, P. Schmidt, and Y. Shin. (1992). "Testing the Null Hypothesis of Stationarity against the Alternative of a Unit Root." *Journal of Econometrics* 54:159-178.

Leuthold, R.M., J.C. Jankus, and J.E. Cordier, J.E. (1989). *The Theory and Practice of Futures Markets*. Lexington Books.

Matthews, W.A., and D.A. Sumner. (2017). "The Drivers of Hay and Forage Crop Exports for the Western United States." 2017 Western Alfalfa & Forage Symposium. Available at: https://alfalfa.ucdavis.edu/+symposium/2017/PDFfiles/Matthews%20Bill.pdf.

Phillips, P.C.B., and P. Perron. (1988). "Testing for a Unit Root in Time Series Regression." *Biometrika* 75(2):355-346.

Pierson, D. (2014, June 08). U.S. farmers making hay with alfalfa exports to China. Los Angeles Times. Available at: https://www.latimes.com/business/la-fi-feeding-china-hay-20140609-story.html.

Putnam, D., W. Matthews, and D.A. Sumner. (2013). "Hay Exports from Western States have Increased Dramatically." *Alfalfa and Forage News*. UC Cooperative Extension, November 2013. Available at: http://ucanr.edu/blogs/blogcore/postdetail.cfm?postnum=11947.

Putnam, D., W. Matthews, and D.A. Sumner. (2015). "Alfalfa and Grass Hay Exports Decline after Seven Years of Dramatic Growth." *Alfalfa and Forage News,* UC Cooperative Extension, April 28, 2015.

Schwarz, T.V., and A.C. Szakmary. (1994). "Price Discovery in Petroleum Markets: Arbitrage, Cointegration, and the Time Interval of Analysis." *Journal of Futures Markets* 14:147-167.

Tejeda, H.A., M.K. Kim, and D.M. Feuz. (2015). "Dynamic Relationships and Price Discovery of Western Alfalfa Markets." Selected paper presented at AAEA annual meeting, San Francisco CA, July 26-28. Available at: ageconsearch.umn.edu/record/205686.

Theissen, E. (2002). "Price discovery in floor and screen trading systems." *Journal of Empirical Finance* 9:455-474.

U.S. Dairy Export Council (USDEC), 2018. Available at: http://www.usdec.org/research-and-data/market-information/us-export-data

U.S. Dairy Statistics, 2017. Available at: https://www.progressivepublish.com/downloads/2018/general/2017-pd-stats-highres.pdf

U.S. Department of Agriculture (USDA) National Agriculture Statistics Services (NASS), 2018. Available at: https://quickstats.nass.usda.gov/.