

# TAILS CURTAILED: ACCOUNTING FOR NONLINEAR DEPENDENCE IN PRICING MARGIN INSURANCE FOR DAIRY FARMERS

MARIN BOZIC, JOHN NEWTON, CAMERON S. THRAEN, AND BRIAN W. GOULD

Livestock Gross Margin Insurance for Dairy Cattle (LGM-Dairy) is a risk management tool for protecting milk income over feed cost margins. In this article, we examine the assumptions underpinning the method used to determine LGM-Dairy premiums. Analysis of the milk–feed dependence structure is conducted using copula methods, a rich set of tools that allow modelers to capture nonlinearities in dependence among variables of interest. We find a significant relationship between milk and feed prices that increases with time-to-maturity and severity of negative price shocks. Extremal, or tail, dependence is the propensity of dependence to concentrate in the tails of a distribution. A common theme in financial and actuarial applications and in agricultural crop revenue insurance is that tail dependence increases the risk to the underwriter and results in higher insurance premiums. We present, to our knowledge, the first case in which tail dependence may actually reduce actuarially fair premiums for an agricultural risk insurance product. We examine hedging effectiveness with LGM-Dairy and show that, even in the absence of basis or production risk, hedging horizon plays an important role in the ability of this tool to smooth farm income over feed cost margins over time. Rating methodology that accounts for tail dependence between milk and feed prices extends the optimal hedging horizon and increases hedging effectiveness of the LGM-Dairy program.

*JEL codes:* G13, Q13, Q18.

The objective of this article is to provide an evaluation of the Livestock Gross Margin Insurance for Dairy Cattle (LGM-Dairy), which is a pilot insurance program administered by the USDA's Risk Management Agency (RMA). LGM-Dairy was created in 2008 to provide dairy producers with individualized protection against catastrophic financial losses. LGM-Dairy allows dairy farmers to insure an income over feed cost (IOFC) margin, which is defined as gross

milk revenue less the declared cost of purchased livestock feed (Gould and Cabrera 2011; Risk Management Agency 2005; Thraen 2012). Various authors have examined the design and use of livestock revenue insurance products for margin risk management (Burdine and Maynard 2012; Hart, Babcock, and Hayes 2001; Liu 2005; Novaković 2012; Turvey 2003; Valvekar, Cabrera, and Gould 2010; Valvekar et al. 2011). However, this analysis is the first to address nonlinearities in dependence between milk and feed prices and to evaluate the performance of alternative LGM-Dairy rating methods that incorporate flexible dependence structures. Analysis of the milk–feed dependence structure is conducted using copula methods, which include a rich set of tools that allow modelers to capture nonlinearities in dependence among variables of interest. Sklar demonstrated that, for any multivariable distribution function, the dependence structure can be modeled separately from univariable marginal distributions. The dependence structure, called a copula, is itself a multivariable

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distribution function with uniform marginal distributions (Genest and Favre 2007; Nelsen 2006; Woodard et al. 2011).

Extremal, or tail, dependence is the propensity of dependence to concentrate in the tails of a distribution (Joe 1997). A common theme in financial and actuarial applications and in agricultural crop revenue insurance is that tail dependence increases the risk to the underwriter, thus increasing insurance premiums (Donnelly and Embrechts 2010; Goodwin 2012; Kousky and Cooke 2009; Liu and Miranda 2010). Our analysis is the first, to our knowledge, to present a case in which tail dependence may actually reduce actuarially fair premiums for an agricultural risk insurance product.

Analysis of the effectiveness of hedging that uses this product complements the analysis of the LGM-Dairy rating method. A wide body of literature has examined optimal hedge ratios and measures of hedging effectiveness (Chen, Lee, and Shrestha 2003; Garcia and Leuthold 2004; Lien and Tse 2002; Williams 2001). More recent work has focused on hedging downside risk (Chen, Lee, and Shrestha 2001; Kim, Brorsen, and Anderson 2010; Mattos, Garcia, and Nelson 2008; Power and Vedenov 2010; Turvey and Nayak 2003). However, there has been limited analysis of the importance of hedging horizon for hedging effectiveness (Chen, Lee, and Shrestha 2004; Ederington 1979; Geppert 1995; Malliaris and Urrutia 1991). We show that, even in the absence of basis or production risk, the hedging horizon plays an important role in the ability of LGM-Dairy to smooth farm IOFC margins over time. For a dairy farm that buys all of its livestock feed needs, we find that a rating method that accounts for tail dependence between milk and feed prices extends the optimal hedging horizon and increases hedging effectiveness.

We proceed with a discussion of the LGM-Dairy rating method, followed by an analysis of assumptions about the milk–feed dependence structure. We find that the Gaussian copula fails to adequately represent the observed data. We also find strong evidence of lower tail dependence between distant milk and corn futures contracts. We propose alternatives to the official LGM-Dairy rating method and analyze cost implications for a variety of insurance policy profiles. Next, we present an analysis of hedging effectiveness. We conclude by discussing implications of the research findings for evaluating other

dairy margin risk insurance products that are offered by the private sector and the federal government in the 2014 Farm Bill.

## Introduction to LGM-Dairy

With the introduction of a market-oriented dairy policy in the late 1980s, U.S. farm-level milk prices have exhibited increased volatility as supply and demand shocks are no longer compensated for by government purchases of excess dairy products. However, despite two decades of increased revenue volatility, open interest in dairy futures and options contracts still accounts for less than 10% of milk marketings. This suggests that dairy producers have used accumulated equity as a buffer to smooth net farm income across consecutive marketing years. More recently, high volatility of livestock feed prices has necessitated a shift in focus from milk revenue to IOFC margin risk management. A dairy producer's ability to borrow against farm equity, combined with the need to protect IOFC margins rather than just milk revenue, implies that an insurance product of high interest to dairy producers would be an affordable insurance policy that protects against rare but deep and prolonged IOFC margin slumps.

The LGM-Dairy insurance product allows dairy farm operators to purchase insurance to protect against decreases in their gross margin, which is defined as the difference between milk revenue and purchased feed costs (Gould and Cabrera 2011). Under this insurance policy, an indemnity at the end of the coverage period is the difference, if positive, between the total guaranteed gross margin determined at the purchase of the insurance contract and the total actual gross margins realized over the desired coverage period. Unlike dairy and grain futures and options contracts, which protect against milk and feed price shocks in a specific month, LGM-Dairy protects against a decline in average IOFC margins over a period of up to ten months.<sup>1</sup> LGM-Dairy offers the ability to insure average margins, rather than a sequence of monthly margins, as one would

<sup>1</sup> LGM-Dairy insurance rules do not allow coverage for the month immediately following the purchase date. The maximum ten-month coverage period protects average margins over the second through eleventh month following the month when the policy is purchased.

do with the purchase of milk puts and livestock feed calls. This renders LGM-Dairy a more affordable risk management tool compared with exchange-traded instruments.

Let  $t$  denote the date of the LGM-Dairy contract purchase, and let  $i = 1, \dots, 10$  denote the  $i$ th month insurable under the LGM-Dairy contract. Let  $p_i^M$  denote expected milk prices and  $M_i$  the insured milk marketings in each of up to ten insurable months. Similarly, let  $p_i^C$  and  $p_i^{SBM}$ , respectively, denote expected corn and soybean meal prices, and let  $C_i$  and  $SBM_i$  denote declared amounts of corn and soybean meal, respectively. Finally, let  $D$  denote the gross margin deductible, which is the threshold decline in expected gross margin at which LGM-Dairy pays indemnities. All decision variables can be stacked into an input vector  $I_t$ , where

$$(1) \quad I_t = [M_1, \dots, M_{10}, C_1, \dots, C_{10}, SBM_1, \dots, SBM_{10}, D]'$$

Given the above, the gross margin guarantee  $G_t$  is calculated as:

$$(2) \quad G_t(I_t) = \sum_{i=1}^{10} (p_i^M - D) M_i - \sum_{i=1}^{10} p_i^C C_i - \sum_{i=1}^{10} p_i^{SBM} SBM_i$$

The realized gross margin  $A_T$  is calculated at the LGM-Dairy contract expiry date  $T$  as

$$(3) \quad A_T(I_t) = \sum_{i=1}^{10} s_i^M M_i - \sum_{i=1}^{10} s_i^C C_i - \sum_{i=1}^{10} s_i^{SBM} SBM_i$$

where  $s_i^M, s_i^C$ , and  $s_i^{SBM}$  are realized milk, corn, and soybean meal prices, respectively, for insurable month  $i$  under a contract sold at time  $t$ .

As stated in the LGM-Dairy rating methodology, expected milk and feed prices are based on the three-day average of class III milk, corn, and soybean meal futures prices, before and including the contract

purchase date.<sup>2</sup> Similarly, terminal prices are calculated as the average of futures prices for the last three trading days before associated futures contracts expiry. For those months for which corn or soybean meal futures are not traded, the associated prices are defined as weighted averages of futures prices, which are obtained from surrounding months for which futures contracts do trade.

An actuarially fair insurance price sets the policy premium equal to expected indemnity. The LGM-Dairy premium at time  $t$ ,  $L_t(I_t)$ , depends on the declared milk marketings, declared feed amounts, and gross margin deductible<sup>3</sup>:

$$(4) \quad L_t(I_t) = E_t [\max(G_t(I_t) - A_T(I_t), 0)]$$

To calculate equation (4), the joint distribution function of actual LGM-Dairy prices must be identified. The joint distribution function has two fundamental structures, its marginal distributions  $F_{M,i}, F_{C,i}$ , and  $F_{SBM,i}$  where  $i = 1, \dots, 10$ , and the assumed dependence structure  $Z$ . According to Sklar (1959), these two structures can be modeled separately as

$$(5) \quad F(s_i^M, s_i^C, s_i^{SBM}) = Z(F_{M,i}(s_i^M), F_{C,i}(s_i^C), F_{SBM,i}(s_i^{SBM}))$$

For purposes of LGM-Dairy premium estimation, the marginal distributions  $F_{M,i}, F_{C,i}$ , and  $F_{SBM,i}$  are assumed log-normal, with their moments obtained from associated futures prices and options premiums. The function  $Z$  is a copula that ‘‘couples’’ these marginal distributions in such a way that it fully contains the dependence structure reflected in the joint distribution function. Given the maximum contract length of ten months, the terminal price joint distribution will be based on information from the third through the twelfth nearby class III milk futures and option prices, the first six nearby corn futures and option prices, and the first eight nearby soybean meal futures and option prices. The joint distribution function will thus have twenty-four degrees of freedom

<sup>2</sup> Under the Federal Milk Marketing Order System, class III milk is the milk used in cheese (except cottage) manufacturing. We use the term *milk* throughout this article to refer to class III milk.

<sup>3</sup> Full insurance premium costs include administrative and overhead fees and a 3% surcharge paid to the Federal Crop Insurance Corporation.

(i.e., twenty-four nonconstrained marginal distributions).

In the official LGM-Dairy rating method, copula methods are not explicitly mentioned. Instead, the method developed by Iman and Conover (1982) is used to couple terminal price marginal distributions. The purpose of the dependence structure is to account for the correlation of price shocks. The official LGM-Dairy rating method represents this dependence structure through a correlation matrix of rank-transformed price shocks.

We define a price deviate  $x_d$  as the difference between realized and expected LGM-Dairy prices:

$$(6) \quad x_d \equiv s_d - p_d \quad d = 1, \dots, 24$$

where  $d = 1, \dots, 10$  corresponds to milk,  $d = 11, \dots, 16$  corresponds to corn, and  $d = 17, \dots, 24$  corresponds to soybean meal prices. Here, we include only those insurable months that directly correspond to commodity futures trading months. Let  $\mathbf{X} = (x_1, \dots, x_{24})'$  be a random vector of price deviates. Given a sample  $\{\mathbf{X}_j\}_{j=1, \dots, n}$ , the pseudo-observations  $\hat{\mathbf{U}}_j = (\hat{U}_{j,1}, \dots, \hat{U}_{j,24})'$  are defined as

$$(7) \quad \hat{U}_{j,d} \equiv \frac{n}{n+1} \hat{F}_d(X_{j,d}) \quad d = (1, \dots, 24)$$

with  $\hat{F}_d(x)$  denoting the univariate empirical distribution function,

$$(8) \quad \hat{F}_d(x) = \frac{1}{n} \sum_{j=1}^n \mathbf{1}\{X_{j,d} \leq x\}$$

$$d = (1, \dots, 24)$$

where  $\mathbf{1}\{\cdot\}$  is the indicator function. Given that  $\hat{F}_d(x)$  returns the number of observations that are less than  $x$ , the pseudo-observations correspond to ranks of the data because  $\hat{U}_{j,d} = R_{j,d}/(n+1)$ , where  $R_{j,d} = (\text{rank of } X_{j,d} \text{ in } \{X_{1,d}, \dots, X_{n,d}\})$ .

The Spearman correlation matrix of the set of pseudo-observations  $\{\hat{\mathbf{U}}_j\}_{j=1, \dots, n}$  is the conditional correlation matrix of the terminal LGM-Dairy milk and feed prices. In the RMA rating method, correlation among feed price shocks is assumed to be month specific. Thus, twelve correlation matrices are calculated, each corresponding to a particular

LGM-Dairy sales event during the year. As such, only one observation of futures price shocks per year can be used. The sample used for feed prices spans 1978–2005 and results in  $n = 28$  for equations (7) and (8) for corn and soybean meal. When the LGM-Dairy rating method was first developed in 2006, only eight years of milk futures data were available (1998–2005). To ensure positive definiteness of the correlation matrix, LGM-Dairy developers restricted the milk–feed correlation submatrix to zero. Further assumptions were imposed on milk–milk correlations, with rank correlation restricted to a function of the distance between contract months only (Risk Management Agency 2005).

Terminal price marginal distributions are coupled into a joint distribution function by using Spearman's rank correlation coefficients of historical price deviates and the procedure developed by Iman and Conover (1982). Although they do not explicitly address the copula issues, Iman and Conover (1982) chose some features of their method primarily to induce elliptical patterns in pairwise plots of input variables. Mildenhall (2006) further demonstrated that the Iman–Conover procedure is essentially the same as using the Gaussian copula. It follows that the LGM-Dairy rating method is, in effect, based on a joint distribution function that can be represented as a set of log-normal marginal distributions coupled with a Gaussian copula.

### Examining the LGM-Dairy Dependence Structure Assumptions

In this section, we examine the official LGM-Dairy rating method assumption that shocks to milk futures prices are not correlated with the shocks to corn and soybean meal futures. The creators of LGM-Dairy claim that, as of 2005, there was no appreciable correlation between milk and feed price shocks. Consistent with this claim, we find that the correlation between the monthly U.S. average milk and corn prices received by farmers from 1990 to 2005 was only 0.07. In contrast, the correlation between milk and corn prices from 2006 to 2013 was 0.57. The latter period was characterized by growing demand for corn for biofuels, which caused an increase in corn prices and a decrease in grain inventories. Lower stocks-to-use ratios

have made grain markets more sensitive to both supply and demand shocks, resulting in increased volatility of corn prices (Wright 2014). Increased concentration in the dairy industry may explain why milk and feed markets have become more tightly integrated (Shields 2010). The percentage of U.S. milk production attributed to farms with more than one thousand cows grew from 35.4% in 2005 to 50.6% in 2012. Large farms tend to purchase a higher percentage of their feed requirements and are generally more price sensitive than more integrated dairy operations (Adelaja 1991; Tauer 1998). Bozic, Kanter, and Gould (2012) find that long-run milk supply elasticity, with respect to feed prices, has substantially increased since 2007.

Furthermore, the correlation between milk and feed price shocks may be substantially stronger for more distant futures contracts. Economic theory of competitive markets with free entry predicts zero long-term economic profits. Consistent with this prediction, Bozic et al. (2012) find that the term structure of IOFC margins has exhibited strongly mean-reverting behavior over the past fifteen years. Because dairy farm profits depend primarily on IOFC margins, it follows that any shock to feed markets that is perceived as persistent will be more fully transmitted to deferred milk futures prices. On the other hand, milk supply is known to be inelastic in the short run because of fixed production factors (Chavas and Klemme 1986). Therefore, we expect rank correlation of milk and feed price deviates for distant LGM-Dairy insurable months to be positive and higher than the correlation for nearby months.

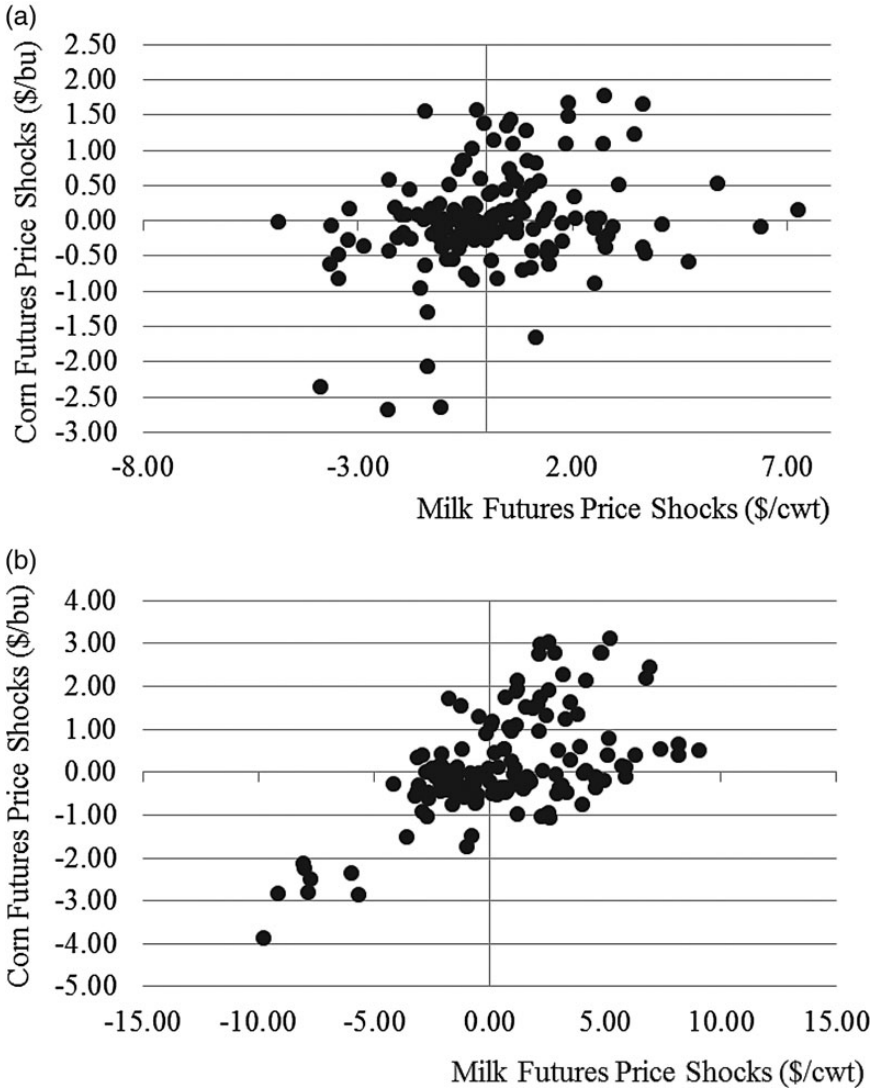
The strength of dependence between corn and milk price shocks may also be contingent on the state of the world. Extreme and rare events may render milk and feed markets more tightly integrated than in a typical environment. For example, demand shocks to milk and feed markets could be less correlated in normal economic times and more correlated during periods of large macroeconomic instability and decreased economic activity.

To examine the milk–corn price shock dependence structure, Figure 1(a) contains the scatterplot for milk and corn price shocks at a four to six-months horizon, with data covering March 1998 through April 2013. Figure 1(b) shows the scatterplot for price shocks using a one-year horizon. Rank

correlation between the fourth nearby milk futures and second nearby corn futures is only 0.22. In contrast, rank correlation between the twelfth nearby milk futures and fifth nearby corn futures is 0.48. The scatterplot in figure 1(b) suggests that corn price shocks with absolute values less than \$1 per bushel have barely any predictive power on the direction of milk prices. However, dramatic corn price surges are much more likely to be accompanied by discernible shocks to milk prices. Of particular interest are the realizations of shocks in the lower left corner of the one-year horizon scatterplot. We find that the eight most adverse shocks to corn prices have been matched by the eight most adverse shocks to milk prices. Codependence in the lower tail is found to be much stronger than it is in the center of the diagram. Therefore, measures of dependence that cannot account for state-specific correlation strength are not likely to account for weakly dependent markets, which are more strongly integrated in extreme circumstances. These scatterplots strongly suggest that the assumption of zero-order correlation between corn and milk prices cannot be supported. Thus, a more robust examination of milk–corn price shock dependence is required.

To examine further whether milk–feed correlations are indeed positive and increasing in time to maturity, we calculate a full Spearman's rank correlation matrix by using futures data from 1998 through 2013. The upper triangle of table 1 lists the selected pairs of price shock correlations. The full correlation matrix can be found in the supplementary appendix online. We find that milk–feed rank correlations increase with time to maturity, as predicted by economic theory, with a maximum milk–corn correlation coefficient of 0.48 achieved for the twelfth nearby milk and fifth nearby corn contract.

As a measure of dependence, correlation is appropriate only in the context of multivariable normal or elliptical models, and it may not adequately capture the apparent propensity of dairy and feed markets to be more closely integrated in extreme market environments (McNeil, Frey, and Embrechts 2010). Such flexibility can be achieved by using copula methods that account for extremal, or tail, dependence. In the case of bivariable copulas, tail dependence relates to the amount of dependence in the upper-quadrant



**Figure 1. Milk versus corn futures price Shocks (a) Futures price shocks at the 4–6 months horizon (b) Futures price shocks at the 1-year horizon**

or lower-quadrant tail of a bivariable distribution (Joe 1997). Extremal dependence is measured by a coefficient of lower tail dependence, defined as

$$(9) \quad \lambda_L = \lim_{u \rightarrow 1} \Pr(U_1 < u \mid U_2 < u)$$

and a coefficient of upper tail dependence, defined as

$$(10) \quad \lambda_U = \lim_{u \rightarrow 1} \Pr(U_1 > u \mid U_2 > u).$$

A Gaussian (normal) copula always exhibits zero tail dependence, no matter how strong the correlation coefficient is (Joe 1997). We use formal statistical tests to examine whether the Gaussian copula can be considered an appropriate approach to modeling dependence between milk and feed price shocks. We use the Cramér-von Mises test, based on Kendall's transforms as suggested by Genest and Rivest (1993) and Wang and Wells (2000). Goodness-of-fit tests for distributions generally proceed by designing a test statistic that summarizes the distance between the empirical distribution

function and the hypothesized cumulative distribution function. Let  $F_\theta$  be the hypothesized cumulative distribution function and  $F_n$  the empirical distribution function. The Cramér-von Mises statistic ( $S_n$ ) is given by

$$(11) \quad S_n = \int_{-\infty}^{+\infty} [F_n(x) - F_\theta(x)] dF_\theta(x).$$

In the test developed by Genest and Rivest (1993), a bivariable copula is first reduced to a one-dimensional distribution function, known as Kendall's transform, with empirical and hypothesized versions of Kendall's transforms used instead of  $F_n$  and  $F_\theta$  in equation (11).

We perform this test for each of the 276 pairs of marginal distributions. In the lower triangle of table 1, we present the resulting  $p$  values. To preserve space, only a subset of  $p$  values is shown. The full table can be found in the supplementary appendix online. At a 95% confidence level, we find that the Gaussian copula is rejected for 99 of 276 pairwise comparisons. Considering the seventh through twelfth nearby milk contracts and the third through sixth nearby corn contracts, we find that a Gaussian copula is rejected for nine of twenty-four pairs at a 95% confidence level and for seventeen of twenty-four pairs at a 90% confidence level. In the supplementary online appendix we further examine the nature of dependence between distant milk and corn futures prices, and we find the Gaussian copula to be inferior to most of the commonly used, bivariable, parametric copulas that exhibit lower tail dependence.

These findings strongly suggest that the LGM-Dairy rating method should be revised to allow a positive dependence structure between milk and feed prices. Revisions should use the method flexible enough to allow strength of the relationship between milk and feed prices to increase with time to maturity and with the severity of negative price shocks.

### Alternative LGM-Dairy Rating Methods

We propose two new LGM-Dairy rating methods. Our first method, Full Correlation, allows for nonzero milk-feed correlations and is flexible enough to allow correlation coefficients to differ based on time to maturity. The second method, Empirical

Copula, goes further and allows dependence among futures price deviates to be stronger in extreme events.

### The Full Correlation Method

The official RMA rating method requires twelve large correlation matrices to be calculated and as many as 887 correlation coefficients to be estimated, despite forcing all milk-feed correlation coefficients to zero. Furthermore, because correlation matrices are month-specific, only one observation of a futures price shock can be collected per calendar year. Under this approach, a minimum of twenty-four years of data is necessary for a twenty-four-variable correlation matrix to be positive definite. Currently, only fifteen years of class III milk futures data exist. Therefore, if correlation matrices are allowed to be LGM-Dairy sales month specific, it would not be possible to relax the zero milk-feed correlation restriction.

Given our previous discussion, we show that the previously described zero correlation restriction is not supported by theory or recent data. Therefore, for the first alternative rating method, we propose a simplifying assumption regarding the correlation structure. In this assumption, each correlation coefficient is stipulated as dependent only on time-to-maturity horizons for each pair of futures price deviates. This nearby-based approach is flexible enough to allow correlation coefficients to depend on time to maturity in addition to distance between contract months. At the same time, this modification greatly simplifies the estimation burden. Under the current premium determination method with LGM-Dairy sales month-specific correlations, allowing for nonzero milk-feed correlation requires estimating more than two thousand correlation coefficients in twelve separate correlation matrices. Under the Full Correlation method, a single  $24 \times 24$  correlation matrix is used.

### The Empirical Copula Method

Rüschendorf (1976) and Deheuvels (1979) introduced the Empirical Copula concept.<sup>4</sup> Given the joint distribution function in equation (5), the copula  $Z$  is a uniquely defined distribution function with domain

<sup>4</sup> In this section, we follow the notation of Blumentritt and Grothe (2013).

**Table 1. Conditional Rank Correlation Matrix (Upper Triangle) and Results of Cramér-von Mises Test of the Gaussian Copula (Lower Triangle)**

			Conditional Spearman's Rank Correlation														
			Class III Milk Futures						Corn Futures				Soybean Meal Futures				
			M7	M8	M9	M10	M11	M12	C3	C4	C5	C6	S4	S5	S6	S7	S8
Cramér-Von Mises Test for Gaussian Copula ( $\rho$ Values)	Class III Milk Futures	M7	—	0.92	0.79	0.68	0.62	0.55	0.28	0.31	0.24	0.20	0.09	0.12	0.08	0.02	0.02
		M8	<b>0.30</b>	—	0.91	0.77	0.67	0.60	0.29	0.33	0.27	0.22	0.14	0.17	0.13	0.06	0.04
		M9	<b>0.01</b>	<b>0.32</b>	—	0.91	0.78	0.67	0.31	0.35	0.33	0.24	0.17	0.21	0.18	0.12	0.08
		M10	<b>0.04</b>	<b>0.07</b>	<b>0.04</b>	—	0.91	0.78	0.33	0.37	0.37	0.28	0.19	0.22	0.22	0.17	0.13
		M11	<b>0.16</b>	<b>0.04</b>	<b>0.07</b>	<b>0.47</b>	—	0.90	0.37	0.39	0.42	0.33	0.21	0.25	0.25	0.23	0.20
	M12	<b>0.25</b>	<b>0.14</b>	<b>0.02</b>	<b>0.03</b>	<b>0.18</b>	—	0.38	0.41	0.48	0.40	0.25	0.32	0.31	0.29	0.30	
	Corn Futures	C3	<b>0.15</b>	<b>0.05</b>	<b>0.09</b>	<b>0.06</b>	<b>0.08</b>	<b>0.21</b>	—	0.76	0.58	0.40	0.53	0.44	0.32	0.24	0.20
		C4	<b>0.25</b>	<b>0.11</b>	<b>0.10</b>	<b>0.13</b>	<b>0.00</b>	<b>0.04</b>	<b>0.11</b>	—	0.77	0.60	0.51	0.54	0.52	0.44	0.38
		C5	<b>0.00</b>	<b>0.04</b>	<b>0.07</b>	<b>0.17</b>	<b>0.07</b>	<b>0.03</b>	<b>0.11</b>	<b>0.09</b>	—	0.83	0.37	0.47	0.56	0.60	0.60
		C6	<b>0.02</b>	<b>0.06</b>	<b>0.03</b>	<b>0.09</b>	<b>0.06</b>	<b>0.01</b>	<b>0.02</b>	<b>0.01</b>	<b>0.12</b>	—	0.23	0.33	0.43	0.53	0.63
	Soybean Meal Futures	S4	<b>0.00</b>	<b>0.21</b>	<b>0.25</b>	<b>0.25</b>	<b>0.59</b>	<b>0.61</b>	<b>0.08</b>	<b>0.24</b>	<b>0.02</b>	<b>0.00</b>	—	0.83	0.68	0.56	0.45
		S5	<b>0.00</b>	<b>0.00</b>	<b>0.00</b>	<b>0.02</b>	<b>0.09</b>	<b>0.21</b>	<b>0.04</b>	<b>0.15</b>	<b>0.04</b>	<b>0.00</b>	<b>0.91</b>	—	0.85	0.72	0.57
		S6	<b>0.10</b>	<b>0.08</b>	<b>0.13</b>	<b>0.13</b>	<b>0.54</b>	<b>0.38</b>	<b>0.03</b>	<b>0.17</b>	<b>0.08</b>	<b>0.07</b>	<b>0.51</b>	<b>0.41</b>	—	0.87	0.73
		S7	<b>0.49</b>	<b>0.34</b>	<b>0.32</b>	<b>0.06</b>	<b>0.00</b>	<b>0.15</b>	<b>0.26</b>	<b>0.04</b>	<b>0.10</b>	<b>0.11</b>	<b>0.69</b>	<b>0.27</b>	<b>0.35</b>	—	0.84
		S8	<b>0.36</b>	<b>0.88</b>	<b>0.46</b>	<b>0.66</b>	<b>0.43</b>	<b>0.10</b>	<b>0.40</b>	<b>0.31</b>	<b>0.36</b>	<b>0.15</b>	<b>0.44</b>	<b>0.41</b>	<b>0.03</b>	<b>0.05</b>	—



$[0, 1]^{24}$  and uniformly distributed margins. Function  $Z$  can be estimated nonparametrically from a sample of futures price deviates  $\{\mathbf{X}_j\}_{j=1, \dots, n}$ . We use futures price data from January 1998 through April 2013. After dropping months with missing data, the total sample size is  $n = 157$ .<sup>5</sup> Using pseudo-observations described in equation (7), the empirical copula is estimated as

$$(12) \quad \hat{Z}(\mathbf{u}) = \frac{1}{n} \sum_{j=1}^n \prod_{d=1}^{24} \mathbf{1}\{U_{d,j} \leq u_i\},$$

$$\mathbf{u} \in [0, 1]^{24}.$$

The Empirical Copula can be further smoothed using kernel functions as explained by Fermanian, Radulović, and Wegkamp (2004). However, the high dimensionality of the LGM-Dairy empirical copula renders this approach infeasible. If no smoothing is done, simulating data based on the empirical copula is a simple bootstrap that is implemented by drawing rows, with replacement, from a matrix of pseudo-observations (Blumentritt and Grothe 2013). Elements of the drawn row-vector are then used as quantiles of marginal distributions, which in the case of LGM-Dairy are defined parametrically.

Alternatively, if pseudo-observations are used directly as quantiles, then marginal distributions can be discretized to points. To remain consistent with the original RMA rating method, we discretize futures and options-based marginal distributions to five thousand points, corresponding to quantiles  $(1/5001) \dots (5000/5001)$ . This is a much finer grid than allowed by the sample size if the direct method is used. To allow for a fine discretization of marginal distributions, we use a modified bootstrap method. Instead of bootstrapping from a matrix of pseudo-observations  $\hat{\mathbf{U}}$ , we draw from a matrix of price deviate ranks, obtained as  $\mathbf{R} = \hat{\mathbf{U}}(n + 1)$ . We first determine the dimensions of an auxiliary matrix  $\mathbf{B}$  to be  $n \lfloor 5000/n \rfloor \times 24$ , where  $\lfloor 5000/n \rfloor$  denotes the largest integer not greater than  $5000/n$ . Matrix  $\mathbf{B}$  is first populated by integers that are uniformly drawn between 1 and 5,000 and then sorted one column at a time.

Matrix  $\mathbf{B}$  can be split into  $n$  blocks of size  $\lfloor 5000/n \rfloor \times 24$ .

The next step is similar to regular empirical copula bootstrapping, as we randomly draw a row (with replacement) of the rank matrix  $\mathbf{R}$ . However, for each column of the selected row  $j$ , each rank  $\mathbf{R}_{j,d}$  determines not the quantile of the  $d^{\text{th}}$  marginal distribution, but the  $\mathbf{R}_{j,d} - \text{th}$  block in the  $d^{\text{th}}$  column of matrix  $\mathbf{B}$ . The specific quantile is finally determined by dividing a random draw from rows  $n(\mathbf{R}_{j,d} - 1) + 1$  to  $n\mathbf{R}_{j,d}$  of the  $\mathbf{B}_d$  column vector by 5,001. The five thousand bootstrap rounds then result in a  $5000 \times 24$  matrix of quantiles from marginal distributions. Distribution of quantiles in each column is uniform, as is needed for any copula. This method allows marginal distributions to be sampled using a finer grid than is allowed by the sample size that underpins the empirical copula, but it does not artificially augment the information available to estimate the empirical copula. Finally, although the Empirical Copula method is rich enough to capture nonlinearities in dependence between included variables, it is simple enough to be implementable for LGM-Dairy insurance purposes.

### LGM-Dairy Premiums and Indemnities under Alternative Rating Methods

The impacts on insurance premiums stemming from the previously described modifications to the LGM-Dairy rating method are likely to be more important for some LGM-Dairy insurance policy profiles than they are for others. The Full Correlation method is not likely to reduce premiums for high-feed insurance policy profiles that protect margins only in nearby months, whereas insurance policies that protect distant months are more likely to be more affordable under this method than they are under the current rating methodology. Likewise, the Empirical Copula method that allows for stronger dependence between milk and feed in extreme circumstances is likely irrelevant for an insurance policy profile that declares minimal amounts of corn and soybean meal. For an insurance policy profile with declared high feed usage, there may be a substantial decrease in the insurance premium.

To examine the impacts of alternative rating methods on LGM-Dairy premiums, we define two representative insurance policy

<sup>5</sup> As implied by our introduction, the class III milk futures and options contract markets were relatively thin during the initial trading years.

profiles: Feed Grower and Feed Buyer. These two policy designs capture two opposing ends of a spectrum of production systems used in the U.S. dairy sector. Some operations pursue an integrated production model, in which livestock feed needs are grown on the farm. These farmers enjoy a natural hedge against increases in feed prices. Instead of incurring feed hedging costs, they manage the cost of raising their own feed. An alternative approach is to outsource all feed production to third parties and use equity capital to support farm expansion and management of a larger dairy herd. This strategy is especially well suited when feed prices are stable because it allows the producer to exploit economies of scale. However, a business model based on buying all livestock feed lacks the resiliency of an integrated feed–milk production model. Unless feed costs are hedged, this strategy can lead to insolvency during prolonged periods of increased feed price.

We define the Feed Grower policy profile such that the insured corn and soybean meal amounts correspond to the minimum feed amounts that must be declared, per LGM-Dairy insurance rules: 0.13 bushels of corn and 0.00081 tons of soybean meal per hundredweight of milk.<sup>6</sup> As for the Feed Buyer policy profile, a briefing paper by the [National Milk Producers Federation \(2010\)](#) provides a reasonable approximation of the feed ration for a typical dairy farm that buys all of its livestock needs. In 2010, the National Milk Producers Federation assembled a dairy-policy working group to construct a representative feed ration using corn, soybean meal, and alfalfa hay. The nutrition specialists in this working group suggested a formulated dairy ration, which the U.S. Congress later modified and adopted. This dairy ration, which is the foundation of the new federal dairy policy, includes 1.0728 bushels of corn, 0.00735 tons of soybean meal, and 0.0137 tons of alfalfa hay per hundredweight of milk ([National Milk Producers Federation 2010; U.S. Congress 2014](#)).

There are no exchange-traded futures or options contracts with alfalfa hay. The LGM-Dairy rules do not allow hay prices to be hedged directly, although suggested conversion coefficients to corn and soybean

equivalents are provided to those dairy producers that wish to cross-hedge hay price risk with corn and soybean meal. To keep our analysis straightforward, we consider a policy that insures only the partial ration that includes corn and soybean meal coefficients, as previously suggested. We do not cross-hedge alfalfa with corn and soybean meal.

In addition to choosing feed amounts per hundredweight of milk, the purchasers of a LGM-Dairy policy must decide on declared milk marketings in each of the ten insurable months. For this analysis, we consider a set of rolling three-month strategies. We assume a new LGM-Dairy policy is purchased every month and that one-third of expected milk marketings are declared for insurable months  $i$ ,  $i + 1$ , and  $i + 2$ . By letting  $i$  vary from 1 through 8, we obtain eight different hedging approaches that differ only in the horizon used for protecting the IOFC margin under this three-month strategy. If  $i = 1$ , then the first three insurable months are protected with the LGM-Dairy policy, which results in a hedging horizon of 30 to 120 days. In contrast, if  $i = 8$ , then the eighth, ninth, and tenth insurable months are protected, with a hedging horizon that spans 240 to 330 days after contract purchase date. Increasing the distance of the hedging horizon increases the LGM-Dairy policy premium, as the margin risk is increasing in time-to-maturity, *ceteris paribus*.

The third and final contract choice involves the deductible level. The chosen deductible level indicates the buyer's risk aversion. Similar to more traditional insurance products, choosing \$0.00 per hundredweight (cwt) deductible results in a relatively high policy premium with a relatively high probability of an indemnity compared with policies with higher deductibles. Choosing a high deductible level (the maximum is \$2.00/cwt) implies that LGM-Dairy is mainly used to protect against catastrophic downside margin risks. Because the primary objective of our analysis is to examine the effects of catastrophic dairy margin insurance, initially we use \$2.00/cwt as the deductible in our analyses. A sensitivity analysis of the impacts under alternative deductible levels is undertaken next.

Table 2 presents results of the analysis of LGM-Dairy premium costs under current RMA and two alternative rating

<sup>6</sup> Similar to hedging with exchange-traded contracts, producers can decide to protect only a share of their expected milk marketings and livestock feed purchases.

methods. We consider Feed Grower and Feed Buyer insurance policy profiles with hedging horizons that cover a three-month period, starting from 30 to 240 days after the contract purchase. We assume that the LGM-dairy contract is available and purchased every month from January 2007 through December 2012. Table 2 presents six-year average per cwt indemnities and policy premiums. As in equation (4) and unlike expected indemnities, realized indemnities are a function of guaranteed and realized margins only. They do not depend on the rating method used. For the Feed Grower policy, average indemnities with a \$2.00/cwt deductible varied from \$0.10/cwt for the 30 to 120 days hedging horizon up to \$0.60/cwt for the 240 to 330 days horizon. Similarly, for the Feed Buyer profile, average indemnities increase from \$0.10 for policies covering nearby months to \$0.35/cwt for the most distant horizon considered.

Because of the 2008–2009 recession and a major drought that occurred in 2012, the realized IOFC margin volatility exceeded the expected volatility from 2007 to 2012. As such, we expect fairly priced insurance to result in indemnities that exceed the premiums paid over the stated period. Under the current RMA rating method, premiums are indeed much lower than indemnities for the Feed Grower policy profile, with net benefits (i.e., indemnity received less premium paid) increasing from \$0.05/cwt for the 30 to 120 days hedging horizon to \$0.35/cwt for the 240 to 330 days horizon. In contrast, net benefits for the Feed Buyer profile exhibit a different picture. Net benefits are negative for all hedging horizons, with losses averaging as high as  $-\$0.23/\text{cwt}$  for the most distant hedging horizon. In contrast with supposed actuarially fair premiums under the current program procedures, we find that even during the period when shocks are higher than expected, the original RMA rating method fails to provide positive net benefits to this policy profile. This finding reinforces the argument that the rating method needs to be updated.

Adopting the Full Correlation or the Empirical Copula rating methodology does not appreciably change premiums under the Feed Grower scenario. In contrast, substantial premium effects are found for the Feed Buyer profile. Under the Full Correlation method, premiums are up to 45% lower than those generated using the actual

RMA method. Using the Empirical Copula method reduces premiums even further, with savings averaging \$0.08/cwt relative to the Full Correlation method for all hedging horizons starting more than five months into the future. Under Full Correlation, premiums are close to realized indemnities. Under the Empirical Copula method, premiums increase net payouts relative to the Full Correlation method by more than three times for the most distant hedging horizon, from \$0.03/cwt to \$0.10/cwt.

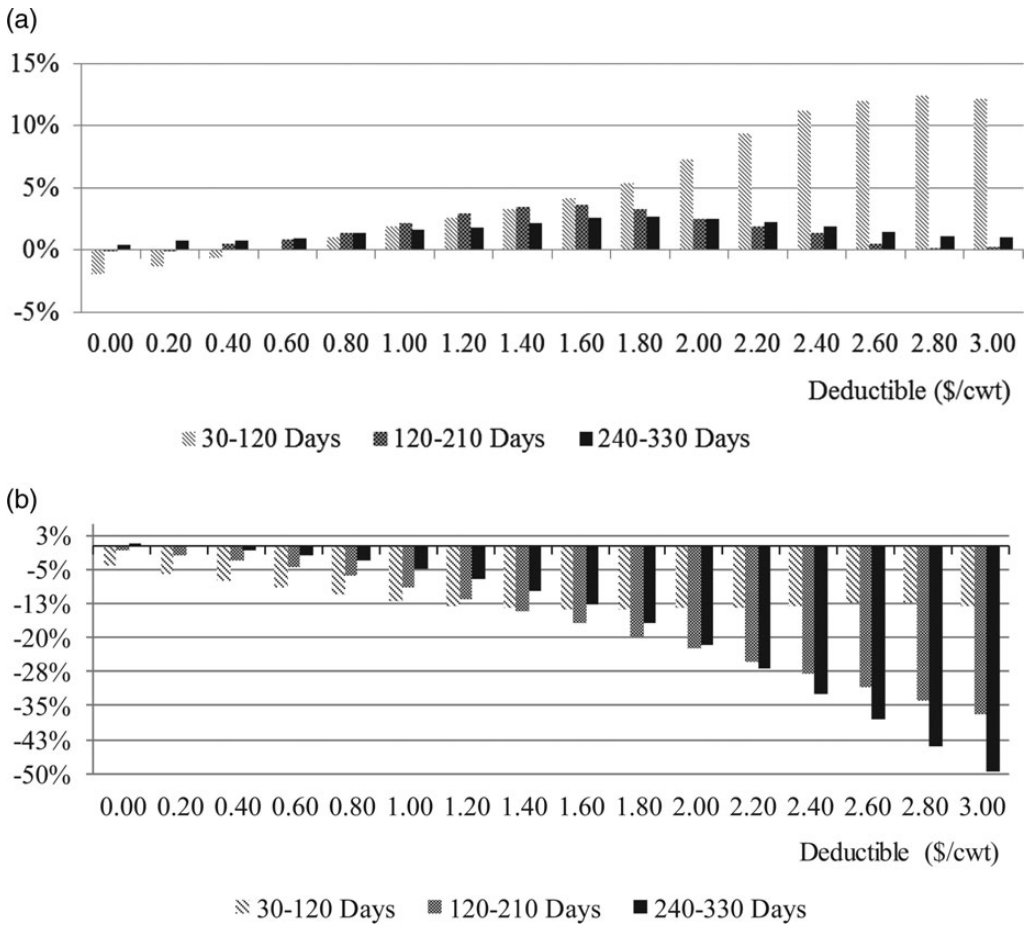
Per current LGM-Dairy insurance policy rules, users cannot choose a deductible level higher than \$2.00/cwt. To put these deductible levels in perspective, consider that the new federal dairy policy, which is based on lessons learned from the LGM-Dairy pilot program, allows margin coverage levels that are up to \$4.00/cwt below the historical average margins. We expect the tail dependence impact on policy premiums to increase in the level of deductible. In figure 2, we further explore the savings under the Empirical Copula method, relative to the Full Correlation method. We allow deductible levels to vary from \$0.00/cwt to \$3.00/cwt. We find that allowing for tail dependence using the Empirical Copula rating method results in substantial premium reductions for the Feed Buyer policy. Compared with the Full Correlation method, the premiums for a hedging horizon of 240 to 330 days under the Empirical Copula method are lower by 4.8% at a \$1.00/cwt deductible, by 21.6% at a \$2.00/cwt deductible, and by 49.7% under at a \$3.00/cwt deductible. In contrast, under the Feed Grower profile, allowing for tail dependence does not produce any premium reductions. To the contrary, premiums actually increase up to 12.4%. We conclude that, although explicitly accounting for tail dependence between milk and feed prices reduces premiums, tail dependence between consecutive class III milk futures prices increases premiums for those policies with minimal feed amounts.

If tail dependence is a characteristic manifested only during a rare event, then one must ask if any given sample contains such an event at its true frequency. For example, our estimation uses data from 1998 through 2013. The extreme realizations of milk and corn price shocks in the lower left corner of the bottom panel of figure 1 are observed at the onset of the 2008–2009 recession. Unless such an event occurs once in fifteen years, on

**Table 2. Effect of Milk–Feed Dependence Assumptions on Hedging Costs, Benefits, and Effectiveness**

Declared Feed	Rating Method	Hedging Effects	Hedging Horizon								
			30–120 Days	60–150 Days	90–180 Days	120–210 Days	150–240 Days	180–270 Days	210–300 Days	240–330 Days	
Feed Grower: Corn: 0.13 bu/cwt Soymeal: 0.0008 ton/cwt	Original Method	Indemnity	0.10	0.19	0.29	0.38	0.46	0.52	0.57	0.60	
		Premium	0.06	0.11	0.16	0.20	0.24	0.28	0.32	0.35	
	Full Correlation	Threshold Semivariance	–22%	–37%	–58%	–76%	–87%	–91%	–91%	–86%	
		Premium	0.05	0.11	0.16	0.21	0.25	0.28	0.31	0.34	
	Empirical Copula	Threshold Semivariance	–22%	–37%	–58%	–76%	–87%	–91%	–91%	–87%	
		Premium	0.06	0.11	0.16	0.21	0.25	0.28	0.32	0.35	
	Threshold Semivariance	–22%	–37%	–57%	–76%	–87%	–91%	–91%	–87%		
		Indemnity	0.09	0.12	0.17	0.23	0.27	0.30	0.33	0.35	
	Feed Buyer: Corn: 1.0728 bu/cwt Soymeal: 0.00735 ton/cwt	Original Method	Premium	0.13	0.22	0.30	0.36	0.43	0.48	0.53	0.58
			Threshold Semivariance	–11%	–17%	–37%	–57%	–41%	–50%	–52%	–40%
		Full Correlation	Premium	0.09	0.15	0.21	0.25	0.29	0.31	0.32	0.32
			Threshold Semivariance	–15%	–20%	–42%	–64%	–51%	–62%	–66%	–59%
Empirical Copula		Premium	0.08	0.13	0.17	0.20	0.21	0.23	0.25	0.25	
		Threshold Semivariance	–15%	–22%	–44%	–68%	–56%	–67%	–70%	–62%	

Note: Indemnity and Premium are in \$/cwt. A \$2.00 deductible is used for these simulations. All results are aggregated over 2007–2012. The average income-over-feed-costs ( $\overline{IOFC}$ ) margin over this period is \$15.23 for the Feed Grower insurance profile and \$8.29 for the Feed Buyer insurance profile. Both policy profiles use a deductible level of \$2.00/cwt. Semivariance reduction is defined relative to the no-hedging threshold semivariance level, where the sample threshold semivariance is calculated as  $\frac{\sum_{i=1}^N \min[IOFC_i - (\overline{IOFC} - \$2.00), 0]^2}{N-1}$ .



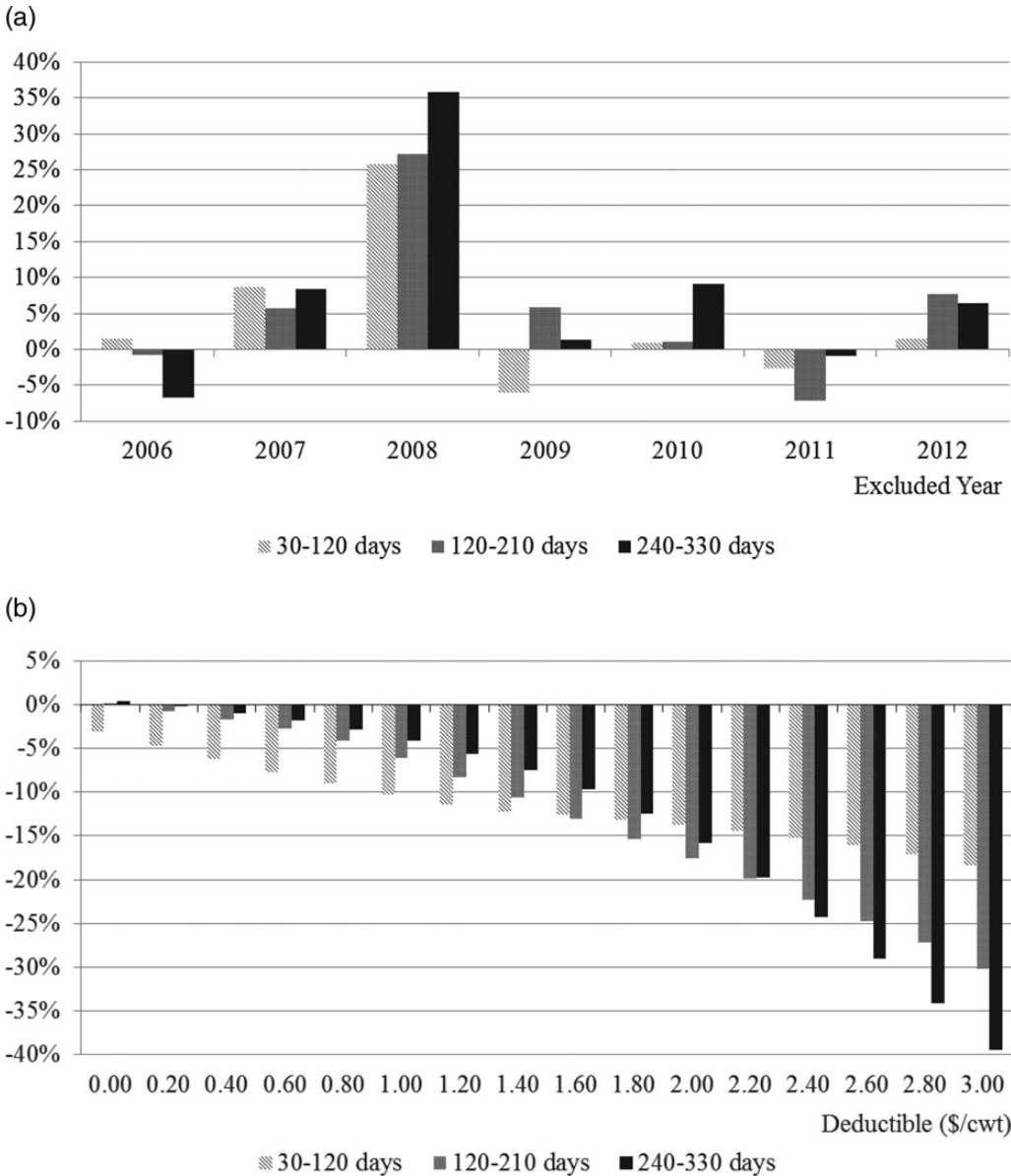
**Figure 2. LGM-Dairy premiums under Empirical Copula relative to the Full Correlation method and under alternative deductible levels (% difference in premiums) (a) Feed Grower policy profile (b) Feed Buyer policy profile**

average, we may oversample these extreme shocks. This is because an additional fifteen years of data are not likely to contain another shock of this magnitude. Oversampling a rare event may bias upward premium reductions from the Empirical Copula method relative to the Full Correlation method. It may also bias upward correlation coefficients, resulting in downward-biased premiums, under the Full Correlation method.

We conduct a jackknife-type sensitivity analysis to illuminate the effects of oversampling a rare event by recalculating average LGM-Dairy policy premiums with the underlying historical price deviates matrix. The matrix is modified so that one year is dropped from the sample. Given the fifteen years of data, there are fifteen sets of fourteen-year histories. Figure 3 shows

premiums under the Full Correlation method for a subset when the excluded year was one of the seven most recent years. By excluding year 2008, the premiums increase up to 36% for the Feed Buyer policy profile. The resulting premiums are still substantially lower than the premiums under the official LGM-Dairy rating method. No change is found for the Feed Grower policy profile.

To examine the influence on premium reductions under the Empirical Copula relative to the Full Correlation method, we reduce the relative frequency of year 2008 to one-fifth of what it is in the original sample. Denote the original sample of price deviates as  $\mathbf{W} = \{\mathbf{X}_j\}_{j=1, \dots, n}$ . Denote with  $\mathbf{W}_{-2008}$  the original sample without 2008 data. The sensitivity analysis is conducted by replicating the sample five times, while allowing data from 2008 to be observed only once in the



**Figure 3. Sensitivity analysis of LGM-Dairy premiums under the Feed Buyer insurance profile (a) Jackknife analysis of premiums under the Empirical Copula with one year excluded from the sample relative to the Empirical Copula method with full sample (b) Oversampling analysis of premium reductions under the Empirical Copula relative to the Full Correlation rating method and with sample augmented as in equation (13)**

augmented sample:

$$(13) \quad \tilde{\mathbf{W}} = [\mathbf{W}' \quad \mathbf{W}'_{-2008} \quad \mathbf{W}'_{-2008} \quad \mathbf{W}'_{-2008} \quad \mathbf{W}'_{-2008}]'$$

This reduction in frequency of the 2008–2009 recession is consistent with the assumption that a shock of similar magnitude occurs only

once in seventy-five years, which is very close to the time lapse between the Great Depression of 1930s and the recession of 2008–2009. We find that the premium savings under the Empirical Copula method relative to the Full Correlation method are lower than they are in figure 2, but they are still substantial.

Premium reductions decline from 21.6% to 15.8% with a \$2.00/cwt deductible and from 49.7% to 39.4% for the \$3.00/cwt deductible. Given this information, we conclude that our initial results regarding the importance of tail dependence are indeed robust.

**Effectiveness of Hedging with LGM-Dairy**

Although allowing for milk–feed dependence may reduce premiums of LGM-Dairy policies, it remains unclear whether LGM-Dairy can indeed be used as an effective risk management instrument. For example, anecdotal evidence suggests that many users of LGM-Dairy were unpleasantly surprised at the inability of their LGM-Dairy policies to effectively smooth IOFC margins in 2012, when high feed prices reduced margins to near historical lows. In this section, we analyze LGM-Dairy hedging effectiveness for a variety of LGM-Dairy insurance policy profiles by incorporating our Full Correlation and Empirical Copula methods.

LGM-Dairy was introduced with an objective to offer an affordable tool for protection against catastrophic downside risks to dairy margins. This is evidenced by its Asian Basket option–style design and by available subsidies that increase with the deductible level. Hedging programs that are based on using LGM-Dairy with high deductible levels as a sole risk management instrument are consistent with the “safety first” preferences introduced by [Telser \(1955\)](#). Measures of risk that address hedging effectiveness in the face of such safety-first preferences are based on the  $\alpha$  order lower partial moments:

$$(14) \quad LPM_\alpha(IOFC; b) = \int_{-\infty}^b (IOFC - b)^\alpha dF(IOFC)$$

where  $F(IOFC)$  is the distribution function of the IOFC margins. In the context of hedging agricultural commodities, such a measure has been used by [Turvey and Nayak \(2003\)](#); [Mattos, Garcia, and Nelson \(2008\)](#); [Power and Vedenov \(2010\)](#); and [Kim, Brorsen, and Anderson \(2010\)](#).

In this analysis, we use threshold semivariance of IOFC margins as a measure of risk, where threshold semivariance is defined

as

$$(15) \quad TSV = E \left[ \min \left( IOFC - (\overline{IOFC} - \$2.00/cwt), 0 \right) \right]^2$$

where  $\overline{IOFC}$  is the historical average margin. If the purpose of pursuing a risk management strategy is to reduce threshold semivariance, then it follows that the effectiveness of any hedging program can be evaluated by

$$(16) \quad v = \left( 1 - \frac{TSV_H}{TSV_N} \right) 100$$

where  $TSV_H$  denotes threshold semivariance under hedging, and  $TSV_N$  is the same measure but under the no-hedging scenario. This measure of hedging effectiveness is well suited for evaluating how well LGM-Dairy protects against catastrophic downside margin risks.

Of particular interest is how the LGM-Dairy rating method influences the optimal length of the hedging horizon. [Ederington \(1979\)](#); [Malliaris and Urrutia \(1991\)](#); [Geppert \(1995\)](#); and [Chen, Lee, and Shrestha \(2001\)](#) examine the effect of hedging horizon length on hedging effectiveness. These studies find that an increase in the hedging horizon generally results in higher hedging effectiveness, which is explained by higher covariance between cash and futures prices at longer horizons. However, a more predictable basis at longer horizons may not be the only reason why hedging months that are more distant can be more effective in stabilizing net revenues. [Bozic et al. \(2012\)](#) argue that shocks to dairy IOFC margins take up to nine months to dissipate. The speed of the mean reversion in IOFC margins is reflected in the term structure of milk futures prices. Consequently, a risk management strategy with a short hedging horizon is inadequate to protect against the full impact of major shocks inducing prolonged low-margin periods. In the aftermath of such a shock, expected IOFC margins decline for those months that are not yet hedged. Attempts to hedge nearby months may then result in guaranteed margins that are already well below the average IOFC margins.

Consider a risk management program based on LGM-Dairy insurance with the Feed Grower profile. In this program, the first

three insurable months are always insured. This strategy results in lower premiums compared with programs that use longer hedging horizons. However, it is ultimately inadequate to protect against major IOFC margin shocks, such as the 2008–2009 recession. Under this program, March, April, and May 2009 were insured at the January 2009 sales event. At that point, futures markets had already incorporated information about the decline in demand for dairy products. In January 2009, the expected average IOFC margin for March–May 2009 was as low as \$9.92/cwt, which was more than \$5.00/cwt below the long-run average of \$15.23/cwt. As this example illustrates, for a hedging program to be consistently effective in smoothing dairy IOFC margins, the hedging horizon must be longer than the average time needed for margins to recover to the long-run average.

In table 2, we measure the effectiveness of hedging with LGM-Dairy under the Feed Grower and Feed Buyer policy profiles. As predicted, hedging effectiveness for the Feed Grower policy increases with the length of the hedging horizon. A maximum reduction in the threshold semivariance of 91% occurs when the hedged period begins seven months after the LGM-Dairy sales event. Under the original RMA rating system and the Feed Buyer policy, maximum hedging effectiveness occurs when the hedged period starts only four months after the sales event. Because the original RMA rating system ignores milk–feed dependence and milk–feed dependence increases with time to maturity, the magnitude of upward bias in LGM-Dairy premiums increases with the length of the hedging horizon.

Indemnities under the Feed Buyer profile increase with time to maturity. This indicates an opportunity for more effective smoothing of IOFC margins if longer hedging horizons are used. However, for horizons longer than four months, upward bias in premiums dominates and thus reduces hedging effectiveness. For the Full Correlation method, hedging effectiveness is nearly identical for four-month and seven-month hedging horizons. Under the Empirical Copula method, we obtain maximum hedging effectiveness at seven months. In conclusion, we find that ignoring the nonlinearity of dependence between milk and feed prices results in negative net payouts for longer horizons. It may also prompt users to use shorter hedging

horizons, which reduces effectiveness of the LGM-Dairy as a hedging instrument for producers who purchase a majority of their livestock feed.

## Conclusions

Finance and actuarial science fields use copula methods for flexible modeling of multivariable dependence structures. Over the last five years, these methods have been adopted in the analysis of agricultural price and revenue risk management. A common theme in research efforts that apply copula methods is that extremal dependence, where present, increases portfolio risk. In this article, we demonstrate that lower-tail dependence exists between milk and corn futures prices and between milk and soybean meal futures prices. Unlike previous applications of copula methods, we find that such extremal dependence actually decreases the price of LGM-Dairy margin insurance because factors inducing exceptionally large declines in milk revenue are likely to induce extreme declines in feed prices as well.

The mean-reverting feature of dairy IOFC margins predicts that hedging will be more effective if longer hedging horizons are used. To test this hypothesis, we analyze the relationship between the length of the hedging horizon and the ability of LGM-Dairy to reduce catastrophic downside risk. We find that hedging effectiveness is substantially higher for longer hedging horizons. The effect is more pronounced when the LGM-Dairy rating methodology is altered to allow for milk–feed tail dependence.

Our study has two policy implications. First, the current rating method for LGM-Dairy is called into question. The current method, which is based on Gaussian copula and data observations through 2005, fails to capture salient features of milk and feed markets. The current rating system should be replaced with the Empirical Copula method, which is presented in this analysis. Second, in scoring federal dairy policy proposals that include margin insurance, evaluation methods should rely on multivariable copula densities that allow for lower tail dependence.

Whereas this work focuses on the structure of dependence among futures prices, additional research on the LGM-Dairy rating method should focus on examining the



assumptions regarding univariate marginal distributions used in the rating method. First, the rating method assumes there are no biases in futures prices or implied volatilities inferred from option premiums. That assumption is particularly suspect for distant class III milk futures and options contracts, which suffer from low liquidity. Second, the rating method assumes all marginal distributions are log-normal. The log-normality assumption may provide computational convenience, but this assumption is known to be inappropriate when applied to the prices of a variety of agricultural products (Fackler and King 1990; Sherrick, Garcia, and Tirupattur 1996). The effect of departures from log-normality on LGM-Dairy premiums needs to be examined.

### Supplementary Material

Supplementary material is available at [http://oxfordjournals.org/our\\_journals/ajae/online](http://oxfordjournals.org/our_journals/ajae/online).

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