Agricultural Systems 104 (2011) 671–678

Contents lists available at SciVerse ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Revenue risk management, risk aversion and the use of Livestock Gross Margin for Dairy Cattle insurance

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ARTICLE INFO

Article history:
Received 9 August 2010
Received in revised form 8 July 2011
Accepted 24 July 2011

Keywords:
Revenue risk management
Revenue insurance
Price variability
Class III milk price
Risk aversion

ABSTRACT

The Livestock Gross Margin Insurance for Dairy Cattle is a federally reinsured insurance program that enables US dairy producers to establish minimum levels of milk income net of feed cost. Given the structure of this program there are an infinite number of possible contract designs based on the choice of deductible level and proportion of production insured. Adding to this complexity, producers vary in their risk preferences, which affect the incentive to insure their margin. It is unclear as to how producers may adopt this program for revenue risk management. This paper investigates the interplay between producer risk preferences, contract design and the subsidization of premium in determining program coverage. We undertook this analysis within an expected utility framework. Optimal contracts under different rates of constant relative rate of risk aversion and subsidies were analyzed using a nonlinear optimization model. We found that total optimal coverage increased significantly with the level of risk of aversion at lower deductibles but as deductible level increased, the level of risk aversion had a lesser impact on total optimal coverages. As expected, at the same deductible and risk aversion levels, inclusion of a premium subsidy increased the total optimal coverage.

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1. Introduction

The US dairy industry has experienced a dramatic increase in variability of milk prices over the last two decades (Fig. 1). Several reasons for this increased variability are a reduction in the level of milk price supports to below market clearing levels, an increasing reliance on export markets as a destination for the marginal milk-based products, a significant growth in milk supply that has outpaced increases in domestic demand and a relatively inelastic domestic demand for a significant segment of the manufactured dairy product portfolio. In response to this increased variability, dairy farm operators are increasing their utilization of dairy-based price risk management systems.

Besides traditional dairy-based futures and options contracts, US dairy producers have had available a dairy revenue insurance program since 2008. This program, known as the Livestock Gross Margin for Dairy Cattle insurance (LGM-Dairy), can be used to reduce income variability by establishing a floor of dairy income net of imputed feed cost (IOFC). As with any insurance program, dairy producers must make several critical decisions when purchasing LGM-Dairy. These include the level of monthly milk production to be insured, the amount of monthly expected feed use necessary to produce the insured production to be declared, and the portion of the IOFC not insured, i.e., the insurance deductible (Gould et al., 2008). Starting in December 2010, the LGM-Dairy policy has undergone significant revisions in that, the maximum deductible was increased from $1.5 to $2 per cwt of milk (1 cwt = 45.36 kg) and premium subsidies, which are positively related to chosen deductible, are now available. According to the new rules, subsidies are available when the IOFC in more than a single month is insured via a particular insurance contract. The subsidy range is from 18% when no deductible to 28% when $0.5 deductible and to 50% when a deductible between $1.10 and $2.00. The USDA Risk Management Agency (http://www.rma.usda.gov/livestock/) provides a summary of the rules governing LGM-Dairy.

Livestock insurance policies are relatively new compared to traditional risk management strategies such as hedging, use of options and entering into forward fixed or minimum price contracts with dairy processing plants. Hart et al. (2003) provided an overview of some of previously established livestock revenue insurance programs and compared them with the use of traditional futures and options risk management systems. They found that livestock producers would benefit from such insurance packages and that these insurance products provide more dollar-for-dollar benefits than the use of traditional put and call options. Subsidies are another important factor that can impact program adoption. In their analysis of the US crop insurance program, Gardner and Kramer (1986) concluded that premiums would have to be

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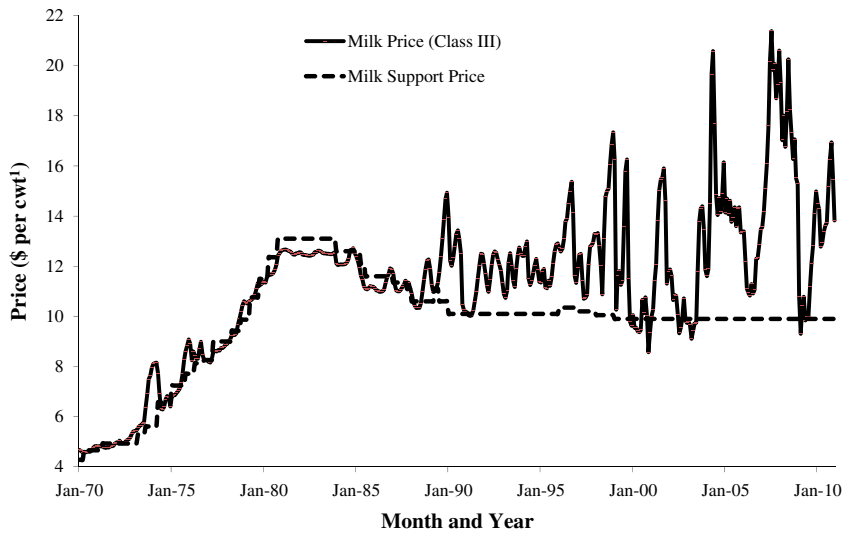
0308-521X/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.agsy.2011.07.004



[1]cwt = hundredweight = 45.36 kg

Fig. 1. Class III milk and support price in the US from January 1970 to December 2010.

subsidized as much as 50% to achieve 50% participation. There is also empirical evidence that price or revenue uncertainty has a significant influence on production decisions (Chavas and Holt, 1996). Also, Just et al. (1999) found that the incentive to participate in insurance programs was largely driven by premium subsidies, although the producer's risk aversion also influenced the participation in Federal Crop Insurance Programs. The problem of rational insurance purchasing from the point of view of an individual facing a specific risk, given individual's wealth level and preference structure was analyzed extensively by Gould (1969), Mossin (1968), and Smith (1968). A study on risk preferences of dairy producers by the analysis of decision making under uncertainty has been undertaken using the expected utility framework since it was first introduced by von Neumann and Morgenstern (1944). The expected utility model implies that rational individuals maximize expected utility with respect to wealth and exhibit diminishing marginal wealth utility. Expected utility theory implies that the decision maker chooses between risky alternatives by comparing their expected utility values, i.e., the weighted sum of outcome utility values multiplied by their respective outcome's occurrence probabilities (Mongin, 1997).

Under the expected utility hypothesis, a decision maker's risk preferences can be represented by a utility function $U(\tau)$ where τ is a random variable. The decision maker makes decisions so as to maximize expected utility, $E[U(\tau)]$, with respect to wealth and the expectation is undertaken based on subjective probability of the value of τ (Chavas, 2004). For example, if there were T income levels, y_i, each of which occurs with probability, p_i, with w decision-maker's initial wealth, the decision-maker's expected utility (EU) can be represented as:

$$EU = \sum_{i=1}^{T} p_i U(y_i|w) \tag{1}$$

where U is the utility derived from the wealth (w) and income (y_i) associated with the ith random outcome.

The risk attitude of the decision maker is directly related to the curvature of the utility function with respect to wealth. Risk neutral individuals have linear utility functions (i.e., $\frac{\partial E(U)}{\partial w} > 0$; $\frac{\partial^2 E(U)}{\partial w^2} = 0$), while risk seeking individuals have convex utility functions (i.e., $\frac{\partial E(U)}{\partial w} > 0$; $\frac{\partial^2 E(U)}{\partial w^2} > 0$), and risk averse individuals exhibit concave utility functions (i.e., $\frac{\partial E(U)}{\partial w} > 0$; $\frac{\partial^2 E(U)}{\partial w^2} < 0$) (Hardaker et al., 2004). By definition, this implies that risk averse individuals perceive the utility derived from the returns from a risky action as being less than the utility of the same level of return that is obtained from a non-risky activity.

Given the above, the objective of this study was to examine the role of risk aversion and premium subsidies on percent of milk related IOFC insured via LGM-Dairy. The expected utility model was used to assess the distribution of risk exposure and the effects of subsidy on this distribution.

2. Simulation of the LGM-Dairy insurance program

2.1. Empirical distributions of simulated indemnities and premium calculation

Earlier work by Valvekar et al. (2010) presented a detailed description of the mechanics of the LGM-Dairy insurance program including a nonlinear optimization model to achieve least cost premium contracts. An overview of program structure and historical performance can be obtained from this previous analysis. The current analysis largely expands Valvekar et al. (2010) by including: (i) the expected utility model within an optimization algorithm, (ii) an increased range of insurance deductibles, and (iii) premium subsidization schedule that became effective with the December 2010 LGM-Dairy contract offering. All variables used in the mathematical formulation are summarized in Table 1.

To determine a LGM-Dairy contract's premium, the RMA uses 5000 simulated indemnities to form an empirical distribution of possible future payouts (RMA, 2009). In this study we replicate these calculations. The indemnities are estimated using simulated prices for Class III milk, corn and soybean meal. The means of these prices are estimated as the average of the futures settle prices observed over the price discovery period defined as the 3 days ending on the last business Friday of each month. Price standard deviations necessary to undertake the above random draws are based on the annualized implied volatility from at-the-money options over the two days prior to the last business Friday of the purchase month. Implied volatilities are calculated using a modified Black–Scholes model (Chesney and Scott, 1989). The Black–Scholes model used to estimate the theoretical options price (OP) is a function of five important elements: The current futures price (FP_t) for month t, the at the money put (call) option strike price for the tth

Table 1
Description of variables used in the expected utility LGM-Dairy optimization model.

Variable	Unit	Description
CF	ton/cwt milk	Expected corn to be fed per month
CV_α	%	Coefficient of variation for 5000 net expected returns with subsidy
CV_β	%	Coefficient of variation for 5000 net expected returns without subsidy
EXPINDEM	$	Expected long-term insurance pay out
FP	$	Current future price
η	–	Random variables affecting risk exposure
IP	$	Insurance premium
m	–	Insurance month
MQ	cwt	Milk production per month
OP	$	Options price
$\Pi\ b(\eta)$	$	Net return before insurance contract
$\Pi(\eta)$	$	Net return after insurance contract
q	days	Time remaining until contract expiration
r	%	Risk free interest rate
$r(\tau)$	–	Absolute risk aversion function
SBF	ton/cwt milk	Expected soybean meal fed
SMP	$/cwt	Simulated milk price
SCP	$/ton	Simulated Corn price
SSP	$/ton	Simulated Soybean meal price
t	–	Price simulation scenario
τ	–	Random variable
θ	–	Constant relative rate of risk aversion
$\theta(\tau)$	–	Relative rate of risk aversion function
$U(\tau)$	$	Utility function
V	–	Volatility
X	$	Option strike price

contract (X_t), time remaining until contract expiration (q_t), risk-free interest rate (r), and volatility (V_t):

$$OP_t = FP_t * N(d_{1_t}) - X_t(e^{-rq_t})N(d_{2_t}) \tag{2}$$

$$\text{where}: \ d_{1_t} = \frac{\ln\left(\frac{FP_t}{X_t}\right) + \left(r + \frac{V_t^2}{2}\right)q_t}{V_t\sqrt{q_t}} \tag{3}$$

$d_{2_t} = d_{1_t} - V_t\sqrt{q_t}$

$N(\bullet)$ = the standard normal cumulative distribution function.

An estimate of volatility for the *t*th futures contract is obtained by solving (2) for V_t. The average of these implied volatilities from call and put options are de-annualized via multiplying by the square root of time remaining until futures contract settlement. The standard deviation of each price is then estimated as the product of the de-annualized volatility and mean price. The simulated distribution for Class III milk takes into account the minimum support price for milk and sets a truncated point at the support price. For this Monte Carlo analysis, desired correlations among random variables are obtained by the variance reduction method (Iman and Conover, 1982). This method takes independent draws from various marginal distributions and re-sorts them to obtain the desired correlations.

2.2. Estimation of risk exposure in the presence of revenue insurance

Given the simulated distribution of indemnities, an estimate of risk exposure is calculated using net expected returns with and without participation in insurance. The initial wealth or the expected net return (π) obtained without insurance is denoted by $\Pi^b(\eta)$, where η represents random variables affecting risk exposure (i.e., milk price, feed cost). In the presence of insurance, the net return becomes

$$\Pi(\eta) = \{(\Pi^b(\eta) - IP) + EXPINDEM\} \tag{4}$$

where $\Pi^b(\eta)$ is the initial wealth or the expected return before entering into an insurance contract, *IP* is insurance premium and *EXPINDEM* is the expected indemnity under LGM-Dairy. To calculate the expected return, $\Pi^b(\eta)$, 5000 monthly simulated prices for Class III milk, corn and soybean meal are used for the 10 month insurance period (RMA, 2009). The initial wealth, $\Pi^b(\eta)$, is represented by:

$$\Pi^b(\eta) = \sum_{m=1}^{10}\sum_{t=1}^{5000}[(MQ_m * SMP_{mt}) - (CF_m * SCP_{mt}) - (SBF_m * SSP_{mt})] \tag{5}$$

where *m* corresponds to a particular month, *t* represents each simulation. MQ_m is the level of monthly milk production, SMP_{mt} is the simulated monthly Class III milk price, CF_m, the amount of corn expected to be fed, SCP_{mt} is the simulated corn price, SBF_m is the amount of soybean meal expected to be fed every month and SSP_{mt} is the simulated price of soybean meal every month.

2.3. Application of expected utility maximization model

In the present study we used the expected utility model, which was evaluated by using reflective alternative risk preferences. Risk preferences are reflected by the curvature of the utility function. Quantification of this curvature is not easy since the utility function is defined only up to a positive linear transformation. A simple measure that is constant for a positive linear transformation of the utility function is the absolute risk aversion function, $r(\tau)$ (Hardaker et al., 2004):

$$r(\tau) = -\frac{\partial^2 U/\partial\tau^2}{\partial U/\partial\tau} \tag{6}$$

Although $r(\tau)$ is unaffected by a positive linear transformation of the utility function, it depends on the units of τ. This unit problem is overcome using the relative risk aversion parameter, $\theta(\tau)$ defined by Arrow (1971) and Pratt (1964) as:

$$\theta(\tau) = \tau r(\tau) \tag{7}$$

where $r(\tau)$ is represented by Eq. (6). The relative risk aversion (θ) function defined above is categorized according to how it changes with respect to increasing wealth, increasing relative risk aversion, decreasing relative risk aversion, and constant relative risk aversion. Under θ one assumes that the preferences among risky prospects are unchanged if all payoffs are multiplied by a positive constant (Hardaker et al., 2004). In this study, we used the generalized forms of utility functions in terms of θ. When the relative risk aversion parameter r is positive, but different from 1 ($\theta > 0$ and $\theta \neq 1$), θ preferences are given by a power function (Hardaker et al., 2004; Chavas, 2004):

$$U(\Pi(\eta)) = [1/(1-\theta)]\Pi(\eta)^{(1-\theta)} \tag{8}$$

where $\Pi(\eta)$ is defined by (4). When $\theta = 1$ constant relative rate of risk aversion preferences are reduced to a logarithmic function (Hardaker et al., 2004; Chavas, 2004):

$$U(\Pi(\eta)) = ln(\Pi(\eta)) \tag{9}$$

Based on the magnitude of the relative risk aversion coefficient, the degree of risk aversion as classified by Anderson and Dillon (1992) are:

Hardly risk averse: $\theta = 0.5$
Normal/somewhat risk averse: $\theta = 1$
Rather risk averse: $\theta = 2$
Very risk averse: $\theta = 3$
Extremely risk averse: $\theta = 4$

Applying the above to the use of LGM-Dairy in Eqs. (8) and (9), the expected utility function for $\theta > 0$ and $\theta \neq 1$, and 5000 simulations is given by:

$$E[U(\Pi(\eta))] = \sum_{t=1}^{5000} \left(\frac{1}{5000}\right) * \left(\frac{1}{1-\theta}\right) * \Pi(\eta_t)^{1-\theta} \quad (10)$$

where $E[U(\Pi(\eta))]$ is the expected utility function for $\Pi(\eta_t)$. Similarly, for $\theta = 1$ the expected utility function is defined by:

$$E[U(\Pi(\eta))] = \sum_{t=1}^{5000} \left(\frac{1}{5000}\right) * \ln(\Pi(\eta_t)) \quad (11)$$

2.4. Assumptions and scenarios for the analyses

We used data for the December 2010 LGM-Dairy insurance contract offering, which covers the period February to November 2010. We selected December 2010 because it was the first month of LGM-Dairy being offered with increased deductibles and premium subsidies. We hypothesized a dairy farm producing 2000 cwt of milk per month. The net expected return obtained without insurance, $\Pi^b(\eta)$ (1–5000), an estimate of the initial wealth, was calculated at 50% of the monthly expected production. We assumed insurance program's default corn (28 lb/cwt milk) and SBM (4 lb/cwt milk) equivalent feed rates (1 lb = 0.4536 kg). We used 8 different scenarios in our analyses: No deductible, \$0.5 per cwt deductible, \$1.1 per cwt deductible and \$2 per cwt deductible with and without subsidy. As initial starting values for our expected utility maximization problem, we used those policy configurations (LGM-Dairy monthly coverages) coming from a least premium cost solution from Valvekar et al. (2010). Following previous study, we used a target guaranteed income over feed cost for the total farm milk (TGIOFC) of \$5 per cwt under each level of deductible analyzed (Valvekar et al., 2010). Table 2 is used to show these policy configurations (starting initial values) for all the four different deductible levels. It is important to note that given these policy configurations, optimal total coverages after expected utility maximization, are relative to these starting values.

2.5. Optimization problem

Friedman and Savage (1948) gave an example of how an expected utility model can provide a representation of risk preferences that range from those that are risk seeking to risk neutral and to risk averse individuals. Using the above expected utility formulation we incorporated (10) and (11) into a model of LGM-Dairy monthly coverage ($\%C_m$). The objective function of the model was then to maximize the expected utility of the net returns from using LGM-Dairy. Hence, at a defined deductible level, the $\%C_m$ were the decision variables. The maximization problem is then represented via the following:

$$\text{Optimal solution} = \max_{\%C_1, \%C_2, \ldots, \%C_{10}} E[U(\Pi(\eta))] \quad (12)$$

$$\text{subject to } 0 \leqslant \%C_m \leqslant 100 \; (m = 1, 2, \ldots, 10) \text{ and } TCP \leqslant 240{,}000 \text{ cwt milk} \quad (13)$$

where TCP is the maximum milk amount to be insured in a LGM-Dairy contract that is capped to 240,000 cwt as per LGM-Dairy contract rules (RMA, 2009). The objective function represented by Eq. (12) was nonlinear with respect to the decision variables as the contract-specific premiums are conditional on contract designed by the decision variables chosen by the producer (Cabrera et al., 2007).

It is important to note that the risk is accounted for via the variance of the 5000 simulated prices for Class III milk, corn and soybean meal during the 10 months under a contract. We estimated the mean and standard deviations of $\Pi(\eta)$ under each policy scenario and θ value when no subsidies were involved. Since the mean and standard deviation vary across simulations, a better estimate of risk, coefficient of variation, was used to show the risk per unit of return and to provide a meaningful risk measure when the expected returns on two alternatives are not the same (Brigham and Houston, 2009). For each simulation we calculated the coefficient of variation for the 5000 simulated net expected returns for the optimal solution under each risk aversion level. Later, we used these values of coefficient of variation under each risk aversion level as an additional constraint in our optimization problem when solving it for scenarios with subsidies. This ensured that the distribution of 5000 net expected returns from the optimal solution with subsidies were within limits of the distribution without subsidy. For example, the coefficient of variation (CV_β) of the optimal solution for a particular θ and deductible level, without subsidy, was 9%. Then, while solving it with subsidy under the same level of θ and deductible, an additional constraint was added to the maximization problem such that the coefficient of variation for the new

Table 2
Livestock Gross Margin for Dairy insurance least cost premium solutions at a target guaranteed income over feed cost (TGIOFC) of \$5 per cwt of farm produced milk for a December 2010 contract under alternative deductibles without premium subsidization.[a]

Coverage month	Deductibles (\$ per cwt[b] milk)			
	\$0	\$0.5	\$1.1	\$2
	% Monthly coverages			
February 2011	100%	100%	100%	100%
March 2011	100%	100%	100%	100%
April 2011	100%	100%	100%	100%
May 2011	69%	87%	100%	100%
June 2011	13%	13%	11%	60%
July 2011	18%	17%	23%	8%
August 2011	17%	9%	21%	27%
September 2011	17%	13%	0%	8%
October 2011	10%	18%	25%	1%
November 2011	54%	56%	55%	77%
Coverage (%)	50%	51%	53%	58%
Least cost premium (\$)	6114	3947	2133	722
NGIOFC[c] (\$ per insured cwt milk)	10.04	9.77	9.37	8.63
Mean of net expected return (\$)	111,122	111,185	111,238	111,279
Net expected return standard deviation (\$)	12,554	13,987	15,444	16,938
Net expected return coefficient of variation of (%)	11%	13%	14%	15%

[a] Solved by using Valvekar et al. (2010). Similar results can be obtained using the "LGM-Dairy Analyzer" at http://future.aae.wisc.edu/lgm_analyzer/. The "LGM-Dairy Analyzer" optimizes subsidized premiums as per new LGM-Dairy policy rules.
[b] 1 cwt = 45.36 kg.
[c] NGIOFC is the net guaranteed income over feed cost under each policy configuration.

distribution under optimal solution with a subsidy (CV_α) should be equal to 9%. This additional constraint can be shown as:

$$CV_\alpha = CV_\beta \text{ for a given level of deductible and } \theta \quad (14)$$

We used the generalized reduced gradient method of nonlinear programming to solve the optimization problem (Lasdon et al., 1974). This method of solution allows for nonlinear constraints on the variables in the optimization process.

Given this formulation of expected utility maximization, it is important to note that the solutions for optimal coverages for alternative θ values are impacted by the distribution of $\Pi(\eta)$. Therefore, before optimization, the statistics of distribution of $\Pi(\eta)$ and the corresponding expected utility were analyzed assuming a constant monthly coverage of 50% (Table 3).

2.6. Starting values for optimization

Least cost premium, insured milk net guaranteed income over feed cost (NGIOFC) and monthly coverages used as starting values for the optimization for different levels of risk aversion are reflected in Table 2. The least cost premium average coverage for no deductible was 50%, the corresponding premium was $6114 and the NGIOFC was $10.04 per cwt of insured milk. Given this optimal solution under no deductible, the average net expected return for the 5000 simulated $\Pi(\eta)$ was $111,122 and the standard deviation (risk) associated with $\Pi(\eta)$ was $12,554. Similarly, the least cost premium average coverage under highest deductible of $2 per cwt milk was 58%, the corresponding premium was $722 and NGIOFC was $9.77 per cwt of insured milk. The average net expected return was $111,279 and the standard deviation (risk) associated with $\Pi(\eta)$ was $16,938. It is evident from Table 2 that with an increase in deductible, the coefficient of variation increased. At $0 per cwt deductible, the coefficient of variation was 11%, whereas at $2 per cwt deductible, it was 15%. In other words, a producer opting for the optimal contract at $2 per cwt deductible, would have higher risk per unit return associated with $\Pi(\eta)$ than a producer opting for an optimal contract with $0 per cwt deductible. As mentioned earlier, these solutions were used as starting values to optimize under the expected utility model at different levels of risk aversion and subsidy.

3. Results and discussion

3.1. Characteristics of the distribution of net expected returns

The statistics of distribution of $\Pi(\eta)$ and the corresponding expected utility are presented in Table 3. Results indicate that the mean of $\Pi(\eta)$ at no deductible was $110,869 with a standard deviation of $10,997. At highest deductible of $2 per cwt milk, the mean $\Pi(\eta)$ was $111,236 with a standard deviation of $15,412. It was interesting to note that with an increase in deductible, the mean $\Pi(\eta)$ increased at a decreasing rate and the standard deviation increased at an increasing rate. The difference between the means $\Pi(\eta)$ at no deductible and $0.1 per cwt deductible was $30 and between $1.9 per cwt and $2 per cwt milk deductible was $8. Similarly, the difference between the standard deviation at $0.1 per cwt milk deductible and no deductible was $59 and between $1.9 per cwt milk deductible and $2 per cwt milk deductible was $237. Earlier research by Cabrera et al. (2009) also confirmed that with every 10 cents increase in the deductible, difference in premium decreases, whereas guaranteed income over feed cost (GIOFC) decreases by exactly 10 cents. Therefore, relative to GIOFC, premiums change very little at higher deductible and so does the potential liability in terms of indemnity. As a result, distribution of $\Pi(\eta)$ gets less dispersed as deductible is increased. Expected utility derived from this distribution at various deductibles for θ of 1 and 4 were also presented in Table 3. Since these are derived from power functions as described in Eq. (10), the expected utility derived at $\theta > 1$ gets from a highly negative exponential form to a less negative exponential form. For convenience of analysis, the expected utility derived was rescaled to reasonable numbers. The expected utility at $\theta = 1$ increased at a decreasing rate from no deductible to $0.7 per cwt milk deductible and then decreased at an increasing rate from $0.8 per cwt milk deductible to $2 per

Table 3
Characteristics of net expected returns ($\Pi(\eta)$) and expected utility at constant relative risk aversion (θ) of 1 and 4.

Deductible ($ per cwt[a] milk)	Mean ($)	Standard deviation ($)	Net expected returns ($\Pi(\eta)$)			Expected utility (utils)	
			Difference in mean returns ($)	Difference in standard deviation of returns ($)	Coefficient of variation (%)	$\theta = 1$	$\theta = 4$[b]
0.0	110,869	10,997	–	–	9.9	1.1611	−2.3179
0.1	110,900	11,056	30	59	10.0	1.1612	−2.3168
0.2	110,929	11,151	29	95	10.1	1.1612	−2.3166
0.3	110,956	11,272	28	121	10.2	1.1612	−2.3170
0.4	110,983	11,417	26	146	10.3	1.1612	−2.3181
0.5	111,007	11,588	25	171	10.4	1.1612	−2.3199
0.6	111,031	11,783	23	194	10.6	1.1612	−2.3225
0.7	111,053	12,004	22	221	10.8	1.1612	−2.3258
0.8	111,074	12,239	21	235	11.0	1.1612	−2.3298
0.9	111,094	12,489	20	250	11.2	1.1612	−2.3344
1	111,112	12,749	18	261	11.5	1.1612	−2.3396
1.1	111,129	13,022	17	273	11.7	1.1612	−2.3455
1.2	111,145	13,297	16	275	12.0	1.1612	−2.3518
1.3	111,160	13,575	15	277	12.2	1.1612	−2.3585
1.4	111,174	13,853	14	279	12.5	1.1612	−2.3658
1.5	111,187	14,129	13	276	12.7	1.1611	−2.3733
1.6	111,199	14,399	12	270	12.9	1.1611	−2.3811
1.7	111,209	14,669	11	270	13.2	1.1611	−2.3895
1.8	111,219	14,929	10	261	13.4	1.1611	−2.3979
1.9	111,228	15,175	9	246	13.6	1.1610	−2.4063
2	111,236	15,412	8	237	13.9	1.1610	−2.4148

[a] 1 cwt = 45.36 kg.
[b] Rescaled expected utility values.

Table 4
Summary of total optimal Livestock Gross Margin for Dairy insurance coverages under various levels of risk aversion and deductibles with and without subsidy.

Deductible ($ per cwt[a] milk)	Subsidy (%)	Least cost premium at TGIOFC of $5 per cwt ($)	Constant relative risk aversion (θ)				
			0.5 (%)	1 (%)	2 (%)	3 (%)	4 (%)
0	0	6014	50	61	66	67	67
	18	5014	70	82	85	87	87
0.5	0%	3947	58	67	69	70	70
	28%	2842	75	80	84	84	84
1.1	0	2133	63	72	75	75	75
	50	1066	85	91	95	95	95
2	0	722	69	69	69	70	70
	50	361	83	83	83	83	83

[a] 1 cwt = 45.36 kg.

Table 5
Livestock Gross Margin for Dairy insurance optimal solution under different risk aversion levels and deductibles without subsidies.

Deductible	Items of comparison	Constant relative rate of risk aversion (θ)				
		0.5	1	2	3	4
No deductible	Total optimal coverage (% milk produced)	50%	61%	66%	67%	67%
	Mean of net expected return ($)	111,083	111,036	111,014	111,010	111,009
	Standard deviation of net expected return ($)	10,986	10,173	9942	9903	9895
	Coefficient of variation (%)	9.9%	9.2%	9.0%	8.9%	8.9%
	Net guaranteed income over feed cost ($/cwt[a])	10.39	10.40	10.40	10.40	10.40
$0.5 per cwt milk	Total optimal coverage (% milk produced)	58%	67%	69%	70%	70%
	Mean of net expected return ($)	111,125	111,093	111,076	111,073	111,073
	Standard deviation of net expected return ($)	12,010	11,494	11,304	11,281	11,281
	Coefficient of variation (%)	10.8%	10.3%	10.2%	10.2%	10.2%
	Net guaranteed income over feed cost ($/cwt)	10.16	10.20	10.24	10.24	10.24
$1.1 per cwt milk	Total optimal coverage (% milk produced)	63%	72%	75%	75%	75%
	Mean of net expected return ($)	111,167	111,148	111,136	111,135	111,135
	Standard deviation of net expected return ($)	13,198	12,930	12,801	12,790	12,792
	Coefficient of variation (%)	11.9%	11.6%	11.5%	11.5%	11.5%
	Net guaranteed income over feed cost ($/cwt)	9.90	9.90	9.93	9.93	9.92
$2 per cwt milk	Total optimal coverage (% milk produced)	69%	69%	69%	70%	70%
	Mean of net expected return ($)	111,219	111,219	111,219	111,219	111,219
	Standard deviation of net expected return ($)	14,858	14,858	14,858	14,858	14,858
	Coefficient of variation (%)	13.4%	13.4%	13.4%	13.4%	13.4%
	Net guaranteed income over feed cost ($/cwt)	9.36	9.36	9.36	9.35	9.35

[a] 1 cwt = 45.36 kg.

cwt milk deductible. Similarly, at $\theta = 4$, expected utility increased at a decreasing rate from no deductible to $0.2 per cwt milk deductible and then decreased at an increasing rate from $0.3 per cwt milk deductible to $2 per cwt milk deductible. Therefore, the expected utility derived from these distributions at higher deductible (associated with higher subsidy) is less than that at lower deductibles. It is also important to note that the utility function for higher level of θ reverses in trend at relatively lower deductibles when compared to lower θ.

3.2. Risk aversion, deductible and total optimal coverage

After expected utility optimization, total optimal coverages were tabulated under different levels of risk aversion and deductibles with and without subsidies. Tables 4–6 are used to show the total optimal coverages, corresponding NGIOFC and coefficient of variation under each scenario. It is also important to note that these optimal coverages were relative to the least cost solutions for total coverages (Table 2) and their interpretations should be made in relative terms to the original least cost solutions. For example, the least cost solution under no deductible was 50% (Table 2). And then a *hardly risk averse person* ($\theta = 0.5$) would opt for 50% coverage, *somewhat risk averse person* ($\theta = 1$) would opt for 61%, *rather risk averse person* ($\theta = 2$) would opt for 66% and those who are *very risk averse* ($\theta = 3$) or *extremely risk averse* ($\theta = 4$) would opt for a total coverage of 67% (Table 4). Similarly, at $1.1 per cwt milk deductible and 50% subsidy, a *hardly risk averse person* ($\theta = 0.5$) would opt for 85% coverage, *somewhat risk averse person* ($\theta = 1$) would opt for 91% and those who are *rather risk averse* ($\theta = 2$), *very risk averse* ($\theta = 3$) or *extremely risk averse* ($\theta = 4$) would opt for a total coverage of 95% (Table 6). These values were relative to 53% optimal coverage under the least cost solution (Table 2). Clearly, the total optimal coverage increased significantly as θ increased from 0.5 to 2 and then remained constant at higher levels of θ. As such, there was hardly any difference in the behavior of a *very risk* or an *extremely risk averse person*. At highest deductible of $2 per cwt milk, the total optimal coverage hardly changed irrespective of different levels of θ. The optimal coverages under highest deductible without subsidy ranged from 69% to 70% across different levels of θ (Table 5) and with subsidy it was 83% irrespective of θ (Table 6). Deductible seems to have a confounding impact on θ. Moreover, the utility function derived at higher levels of θ reverses in trend at relatively lower deductibles when compared to lower levels of θ (Table 3), therefore, the diminishing expected utility beyond these deductible levels prompted for relatively lower levels of coverage.

3.3. Risk per unit return for $\Pi(\eta)$

It is also evident that the coefficient of variation or the risk per unit return of $\Pi(\eta)$ decreases with an increase in θ (Table 5). For an

Table 6
Livestock Gross Margin for Dairy insurance optimal solution under different risk aversion levels and deductibles with subsidies.

Deductible and corresponding subsidy	Items of comparison	Constant relative rate of risk aversion (θ)				
		0.5	1	2	3	4
No deductible and 18% subsidy	Total optimal coverage (% milk produced)	70%	82%	85%	87%	87%
	Mean of net expected return ($)	112,743	113,030	113,094	113,264	113,261
	Standard deviation of net expected return ($)	11,149	10,356	10,140	10,115	10,107
	Net guaranteed income over feed cost ($/cwt[a])	10.17	10.32	10.38	10.55	10.54
$0.5 per cwt milk and 28% subsidy	Total optimal coverage (% milk produced)	75%	80%	84%	84%	84%
	Mean of net expected return ($)	113,013	113,119	113,252	113,271	113,272
	Standard deviation of net expected return ($)	12,209	11,713	11,529	11,510	11,509
	Net guaranteed income over feed cost ($/cwt)	9.98	10.12	10.15	10.16	10.16
$1.1 per cwt milk and 50% subsidy	Total optimal coverage (% milk produced)	85%	91%	95%	95%	95%
	Mean of net expected return ($)	113,404	113,652	113,805	113,829	113,829
	Standard deviation of net expected return ($)	13,469	13,220	13,112	13,099	13,099
	Net guaranteed income over feed cost ($/cwt)	9.74	9.81	9.84	9.85	9.85
$2 per cwt milk and 50% subsidy	Total optimal coverage (% milk produced)	83%	83%	83%	83%	83%
	Mean of net expected return ($)	112,524	112,524	112,523	112,523	112,523
	Standard deviation of net expected return ($)	15,022	15,022	15,022	15,023	15,023
	Net guaranteed income over feed cost ($/cwt)	9.36	9.30	9.30	9.30	9.30

[a] 1 cwt = 45.36 kg.

extremely risk averse person opting for $0.5 per cwt milk deductible, the coefficient of variation for $\Pi(\eta)$ was 10.2% and a *hardly risk averse person* would have 1.05 times more risk associated with $\Pi(\eta)$ (10.8%) than an *extremely risk averse person.* Interestingly, the coefficient of variation for $\Pi(\eta)$ under the least cost solution for the same level of deductible was 13% (Table 2). Therefore $\Pi(\eta)$ under optimal solution for different θ and no deductible was less risky than the least cost solution. At highest deductible of $2 per cwt milk, however, the coefficient of variation associated with $\Pi(\eta)$ was constant at 13.4%, but still less risky than the least cost solution. Therefore, the risk per unit return associated with the 5000 simulated distributions of $\Pi(\eta)$ was reduced considerably after expected utility maximization, compared to the least cost solutions. Results also indicated that higher the level of risk aversion, lower was the risk per unit return associated. The case for $2 per cwt milk deductible is an exception because θ has very little impact on the optimal coverages when high deductibles. As earlier mentioned, deductible had a confounding effect on θ, more so at higher deductibles, since higher deductible corresponds to a higher risk retained by a producer.

3.4. Impact of subsidy and deductible

According to the new (December 2010) LGM-Dairy policy rules the level of subsidy is tied to the level of deductible. As expected, for the same level of θ, an increase in subsidy prompts for a higher optimal coverage under the same deductible (Tables 4–6). Under no deductible and no subsidy, a *rather risk averse person* ($\theta = 2$) would opt for 66% coverage (Table 5). But with subsidy, as the premium is reduced by 18% subsidy, the same individual would opt for 85% of total coverage (Table 6). Similarly, at $1.1 per cwt milk deductible, for θ of 2 through 4, the total optimal coverage without subsidy was 75% (Table 5) and with a 50% subsidized premium, the optimal coverage increased to 95% (Table 6). At $2 per cwt deductible, the total optimal coverage without subsidy ranged from 69 to 70% across different θ (Table 5) and with subsidy the total optimal coverage was 83% irrespective of θ (Table 6). This also indicates that the total optimal coverages increased significantly with θ at lower deductibles and as the deductibles increased to $2 per cwt milk, the total optimal coverage was constant and θ had lesser impact on total optimal coverages, irrespective of subsidy.

Actual trends in the sales of LGM-Dairy policies after subsidies strongly corroborate our results. The new policy with premium subsidization had increased the number of policies sold and the milk covered under LGM-Dairy significantly. From August 2008 through November 2010 (28 month period), the number of policies sold before subsidies were 545 and the total insured milk under the policy was 9810,486 cwt. However, from December 2010 through March 2011 (4 month period), the number of policies sold after the implementation of subsidy was 1062 and the total insured milk was 38,672,408 cwt milk (RMA, 2011). This indicates 95% increase in the number of policies sold and 294% increase in the amount of milk insured in just four months after the implementation of subsidy, compared to the previous 28 months without subsidy. The policies sold and milk insured would have even been greater, but the 2010–2011 underwriting capacity of LGM-Dairy policy was reached during the March 2011 contract period and no more LGM-Dairy policies are being sold until the next fiscal year.

4. Conclusions

This study investigates the impact of subsidies on farmers' LGM-Dairy coverage decisions according to risk aversion preferences. An optimization model was created having the expected utility maximization of the net returns as the objective function. It was found that the total optimal coverages increased significantly as the risk of aversion increased from 0.5 to 2 and thereafter the total optimal coverages hardly changed. Results also indicated that the optimal coverages increased significantly as the deductibles were increased to $1.1 per cwt milk deductible. However, at higher deductibles such as $2 per cwt milk, the total optimal coverage was constant and the risk of aversion had lesser impact on total optimal coverages. Higher deductibles had a confounding effect on risk aversion because higher deductible corresponded to higher risk retained by a producer. Results also indicated that premium subsidization increased significantly the optimal LGM-Dairy coverages under the same level of deductible and risk aversion. Actual sales of LGM-Dairy policy corroborate our findings regarding the impact of premium subsidization on the adoption of LGM-Dairy. The insured milk under LGM-Dairy in the US increased almost threefold since the LGM-Dairy premium subsidization. Therefore, the impact of premium subsidization on LGM-Dairy and the importance of LGM-Dairy as a revenue risk management tool for the US dairy farm industry cannot be overstated.

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