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Economic impacts of reduced milk production associated with papillomatous digital dermatitis in dairy cows in the USA

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The goal of this study was to measure the economic impacts of reduced milk production associated with papillomatous digital dermatitis (PDD) in dairy cows in the USA, and of specific risk factors for PDD, in 1996. The method applied was an economic-welfare analysis of producer and consumer surplus, with the GUM Workbench used to analyse uncertainties in the measurements. Reduced milk production associated with PDD was found to reduce consumer surplus by \$750 million ± \$580 million, and to increase the economic surplus of producers by \$560 million ± \$470 million, with a net economic loss of \$190 million ± \$130 million. An examination of the economic effects of specific epidemiologic risk factors for PDD showed that having dairy cows that were not born on the operation had important economic consequences associated with the disease, as did the type of land to which dairy cows had access during the winter months and the type of flooring on which cows walked. Washing hoof-trimming equipment between cows was an important biosecurity measure that was associated with reduced PDD. The epidemiologic model used also implicated hoof trimmers who trimmed cattle hooves on other operations as having an important economic impact associated with this disease, although this finding may have been erroneous.

Keywords: Cost of disease, dairy cows, dairy production, economic surplus, NAHMS, Welfare analysis, uncertainty propagation.

Papillomatous digital dermatitis (**PDD**) is a skin disease of the bovine digit, and is characterized by lesions which range in appearance from 'moist and strawberry-like' to 'raised, hairy and wart-like' (Read & Walker, 1998). The lesions can be very painful, and affected dairy cows may avoid moving and may stop eating, which lowers milk production, decreases the condition of the body, and can lead to reproductive problems and increased likelihood of culling (Argáez-Rodríguez et al. 1997). PDD appears within dairy herds as lameness outbreaks of variable severity (Argáez-Rodríguez et al. 1997). Costs associated with the disease can have an adverse financial impact on affected dairy producers (Nutter & Moffitt, 1990; Rebhun et al. 1980).

This particular malady was first described by Cheli & Mortellaro (1974), and is an increasingly important disease of dairy cows worldwide (Argáez-Rodríguez et al. 1997). The economic impacts of PDD in dairy cows have not been well defined. In a study of PDD on one dairy operation in Mexico, Argáez-Rodríguez et al. (1997) found that purchased cows were much more likely to be affected by PDD than cows that had been born on the farm, and that affected cows had a higher average number of days between calving and conception. Argáez-Rodríguez et al. (1997) reported that milk production was not significantly different between cows that were affected and cows that were not affected by PDD (possibly because the study's scope was limited to one dairy farm). In a study of two New York dairy operations, Warnick et al. (2001) found that milk production did decrease significantly in lame cows.

In an examination of the impact of clinical lameness (including sole ulcers, white line disease, interdigital necrobacillosis and PDD) on the milk yield of dairy cows, Green et al. (2002) found that milk loss per affected cow averaged 360 kg with a 95% confidence interval that ranged from 160 to 550 kg. Green et al. (2002), whose study was based on data from 900 cows on five farms in Gloucestershire, UK, stated that their sample size was not large enough to be able to provide an estimate of the impact (on milk production) of each cause of lameness, and thus the 95% confidence interval was rather broad.

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As part of a national survey (dubbed the 'Dairy '96 Study') of US dairy producers, the National Animal Health Monitoring System (**NAHMS**), of the US Department of Agriculture (**USDA**) Animal and Plant Health Inspection Service (**APHIS**), reported that 17·2% (SE = 0·6) of US dairy cows had PDD in 1996 (USDA, APHIS, 1997). USDA, APHIS (1997) felt that its estimate concerning the number of cows affected by PDD should be viewed as conservative, because many cases were probably unrecognized by the herd managers who responded to the survey questions. USDA, APHIS (1997) performed an epidemiologic risk-factor analysis, and identified region, herd size, type of land lactating cows accessed, flooring type where lactating cows walked, having cows that had been born off the operation, using hoof trimmers who trimmed cattle hooves on other operations, and not washing hoof-trimming equipment between cows, as important herd-level factors that predisposed an operation to a high incidence of PDD. USDA, APHIS (1997) did not undertake to study the economic impacts of the disease. Wells et al. (1999) repeated the results of USDA, APHIS (1997) in a separate report.

Relatively little academic work seems to have been accomplished on the economic importance of PDD, which causes lameness of varying severity. One purpose of the present study was to use available data to estimate changes in consumer and producer surplus, and the total loss to the US economy, caused by reduced milk production associated with PDD in dairy cows. Consumer surplus is the difference between what consumers are willing to pay for a product, and the amount that consumers actually pay at the market price (Losinger, 2005b). A Demand Curve's downward slope demonstrates that as the market price increases, consumers willingly purchase a greater quantity. The total consumer surplus is the area above the point where the demand and supply curves intersect (which is the actual market price and quantity), but below the demand curve. Consumers who would have been willing to pay more than the market price for their milk, and who only have to pay the market price, enjoy a surplus that they may spend on other goods. Producer surplus is the difference between the amount of money that producers receive for a commodity, and the amount that they would be willing to accept to supply a given quantity.

A second purpose was to measure the economic impacts of eliminating – from the US population of dairy cattle – exposure to specific risk factors to PDD. Decision-makers could use these results to determine where to concentrate efforts to control PDD.

Materials and Methods

An economic welfare analysis was performed to measure changes in producer and consumer surplus, based on the assumption of linear demand and supply curves and a parallel supply shift. Welfare analysis seeks to measure the gains or losses that individuals experience as a result of price changes (Nicholson, 1995). The procedures followed were similar to those developed by Losinger (2005) to evaluate the economic impacts of Johne's disease. Eckert & Leftwich (1988) point out that consumer surplus, as measured under an ordinary demand curve, is an approximation and not an exact measurement: the smaller the income effects of a price change relative to the substitution effects, the more accurate the measurement will be. In the USA, milk is cheap enough (relative to average incomes) that the income effects (to consumers) of ordinary price fluctuations in milk are negligible. Eckert & Leftwich (1988) point out that 'most economists believe that for most goods the measure is accurate enough to be a useful tool of analysis.' For poor Americans, the income effects of changes in the price of milk may not be negligible: further research would be required to examine the impacts of PDD on specific classes of consumers. Lindner & Jarrett (1978) and Miller et al. (1988) describe the impacts that various assumptions (about the way in which supply curves shift) can have on the computation of the change in producer surplus. If the original and shifted supply curves approach each other as they get closer to the horizontal axis (which Lindner & Jarrett (1978) call a 'divergent' shift), then the absolute value of the change in producer surplus will be reduced. If the original and shifted supply curves separate from each other as they approach the horizontal axis (which Lindner & Jarrett (1978) term a 'convergent' shift), then the absolute value of the change in producer surplus will be higher. The assumptions of linear demand and supply curves and parallel supply shift are fairly common working assumptions among economists who study the economic impacts of animal diseases. For example, Ebel et al. (1992) assumed linear demand and supply curves, and parallel supply shifts, to measure the change in producer surplus resulting from the National Pseudorabies Eradication Program. Forsythe & Corso (1994) subsequently identified an error in the analysis of Ebel et al. (1992) and presented corrected estimates of welfare effects but still assumed linear demand and supply curves and a parallel shift in supply.

Table 1 summarizes the input quantities used in this analysis. The model equations used were similar to those provided by Losinger (2005), but with the change in the total quantity of milk produced being estimated as the product of the impact of lameness on milk production, and the number of US cows with PDD in 1996. GUM Workbench (Metrodata GmbH, 1999) was used to generate the estimates and uncertainties for the changes in consumer and producer surplus, and total economic loss caused by reduced milk production associated with PDD in dairy cows. GUM Workbench is specialized software that computes estimates, combined standard uncertainties, and expanded uncertainties following the recommendations of the International Organization for Standardization (**ISO**) (1995). The 'uncertainty' of a measurement is a

Table 1. Input quantities used in the computation of economic impacts of reduced milk production associated with PDD in US dairy cows, their uncertainties and sources

Input quantity	Distribution	Value	Standard Uncertainty	Degrees of Freedom	Source
Kg/cow milk-production decline in cows with lameness†	Rectangular‡	355	195	∞	Green et al. 2002
Percent of US dairy cows that had PDD in 1996	Normal	17·2	0·6	50§	USDA, APHIS, 1997
Number of dairy cows	Normal	9 327 000	122 000¶	50§	USDA, NASS, 1999
Kg milk produced in 1996	Normal	70 003 million	630 million¶	50§	USDA, NASS, 1999
Mean price of milk in 1996 ($/kg)	Normal	0·328	0·004¶	50§	USDA, NASS, 1999
Price elasticity of demand for milk	t	−0·25	−0·05	14	Meilke et al. 1996
Price elasticity of supply for milk	Rectangular†	0·56995	0·18855	∞	Adelaja, 1991

† Effects of PDD are assumed to be the same as the effects of lameness in general

‡ For the rectangular distribution, the value is the midpoint between the upper and lower limits, and the half-width of this limit is listed in the uncertainty column. Degrees of freedom are infinite by definition (Metrodata GmBH, 1999)

§ For normally distributed Type B data, the GUM Workbench assigns a default value of 50 to the degrees of freedom (Metrodata GmBH, 1999)

¶ Uncertainties are based on USDA, NASS, 1996

Table 2. Uncertainty budget for the change in consumer surplus as a result of reduced milk production associated with PDD in US dairy cows in 1996

Input quantity	Sensitivity coefficient†	Uncertainty contribution‡	Index§
Reduced milk production in lame dairy cows (kg/cow)	$-2{\cdot}1\times10^{6}$	$-2{\cdot}4\times10^{8}$	69·3%
Percent of US dairy cows that had PDD in 1996	$-4{\cdot}4\times10^{7}$	$-2{\cdot}6\times10^{7}$	0·8%
Number of dairy cows	$-8{\cdot}1\times10^{1}$	$-9{\cdot}8\times10^{6}$	0·1%
Kg milk produced in 1996	$4{\cdot}4\times10^{-5}$	$2{\cdot}8\times10^{4}$	0·0%
Mean price of milk in 1996 ($/kg)	$-2{\cdot}3\times10^{9}$	$-4{\cdot}9\times10^{6}$	0·0%
Price elasticity of demand for milk	$-3{\cdot}2\times10^{9}$	$-1{\cdot}6\times10^{8}$	29·7%

The final estimate for the change in consumer surplus is $-\$7.50\times10^{8}$, with a standard uncertainty of $\$2.88\times10^{8}$ and 160 df. The resulting value and expanded uncertainty, with a coverage factor of two, is then:

−$750 000 000 ± $580 000 000

† $\partial y/\partial x_i$: describes how the estimated value of the measurand, *y* (i.e. consumer surplus) varies with changes in the estimated value of the input quantity x_1, x_2, … (i.e. reduced milk production in lame dairy cows, percent of US dairy cows that had PDD in 1996, etc)

‡ Product of the standard uncertainty (Table 1) and the sensitivity coefficient. The sum of the squares of the values in this column equals the square of the uncertainty in the estimated value of the measurand *y*

§ Percent contribution to the square of the measurand's uncertainty. This is 100 times the ratio of square of the input quantity's uncertainty contribution to the square of the uncertainty in the estimated value of the measurand. This column sums to 100%

parameter (associated with a measurement result) that characterizes the dispersion of the values that could reasonably be attributed to the measurand (ISO, 1995). The 'standard uncertainty' consists of two types of evaluations: a 'Type A' evaluation (which is derived from the statistical evaluation of a series of data, often called the standard error, SE); and a 'Type B' evaluation (where the method of evaluation of the uncertainty was from other than a statistical evaluation of a series of data, and ranges from reference books to educated guesses) (ISO, 1995). The 'combined standard uncertainty' is the standard uncertainty of the result of a measurement when the result is obtained from the values of a number of other quantities, and is derived as described below. The 'expanded uncertainty' is an interval (also known as a 'confidence interval') that encompasses a large fraction of the distribution of values that could reasonably be attributed to the measurand, and is derived by multiplying the standard uncertainty by a coverage factor (which usually ranges between 2 and 3) (ISO, 1995).

GUM Workbench calculates sensitivity coefficients by applying numerical partial differentiation, uses Taylor-series approximation to compute combined standard uncertainties, and Satterthwaite's approximation to compute combined degrees of freedom (Metrodata GmbH, 1999). The 'sensitivity coefficient', which is the partial derivative of the measurand with respect to an input quantity ($\partial y/\partial x_i$), describes how the estimated value of the measurand, *y*, varies with changes in the estimated value of the *i*-th input quantity (ISO, 1995). For example, Table 2 shows that

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the sensitivity coefficient of the input quantity 'reduced milk production in lame dairy cows' was $-2{\cdot}1\times10^{6}$. This indicates that if milk production in lame dairy cows were reduced by 1 kg/cow (and everything else remained unchanged), then consumer surplus would fall by $2.1 million.

The fundamental Taylor-series formula for the combined standard uncertainty of a measurement is:

$$u(y)=\sqrt{\sum_{i=1}^{N}\left[\frac{\partial y}{\partial x_i}\right]^2 u^2(x_i)+2\sum_{i=1}^{N}\sum_{j=i+1}^{N}\frac{\partial y}{\partial x_i}\frac{\partial y}{\partial x_j}u(x_i,x_j)}$$

where $u^2(x_i)$ is the square of the standard uncertainty of the i-th input quantity, and $u(x_i x_j)$ represents the covariance between the i-th and j-th input quantities (ISO, 1995). In the case where the input quantities are uncorrelated, the covariance term drops from the equation, and the estimate of the uncertainty of y is simply the square root of the sum of the squares of the products of the individual sensitivity coefficients and uncertainties of the input quantities.

This analysis used the 95% confidence interval from Green et al. (2002) of the reduced milk production in lame cows, with the upper and lower bounds of the confidence interval set as the limits, but with a rectangular distribution. As mentioned above, Green et al. (2002) provided a confidence interval for reduced milk production associated with lameness, but did not provide estimates of reduced milk production associated with specific causes of lameness, because the sample size was too small. However, Green et al. (2002) reported that digital dermatitis was one of the most common causes of lameness in their study, and no better estimate of the production impact of PDD appears to be available. Kessel (2003) specifically recommends using the rectangular distribution when a researcher considers that all values between two limits have the same likelihood, and where the researcher cannot prefer specific values without having more knowledge. The best available estimate of the milk-production impact of PDD is that it lies somewhere between 160 and 550 kg/cow and, because this interval included lamenesses due to causes other than PDD (Green et al. 2002), there is no reason to prefer the midpoint of this interval over other points within this interval.

The reduction in milk production (associated with PDD) was estimated by multiplying the milk-production decline by the number of dairy cows and the percent of dairy cows that had PDD (divided by 100) in 1996. The National Agricultural Statistics Service (**NASS**) of the USDA indicated that the population of dairy cows in the US was 9 372 000 and that these dairy cows that produced 70 003 million kg of milk at a mean price of $0.328 per kg (USDA: NASS, 1999). NASS provided relative uncertainties of 0·9% for milk production, and 1·3% for the population of dairy cows during 1996 (USDA: NASS, 1996). Since NASS did not provide information on the uncertainty of the estimate of the price of milk during 1996, a relative uncertainty of 1·3% was used as a conservative estimate. When an uncertainty for an input is unknown, ISO (1995) permits analysts to use an educated guess, and this was the larger of the uncertainties given for milk production and for the number of dairy cows.

The price elasticity of demand (Nicholson, 1995) measures the extent to which changes in the price of a good relate to changes in the quantity purchased, and is defined as the relative change in the quantity purchased divided by the relative change in the price. Meilke et al. (1996) provided a list of 15 different researchers' estimates of the price elasticity of demand for fluid milk in North America. Estimates ranged from −0·04 to −0·73, with a mean of −0·25 (SD=0·20, SE=0·05) (Meilke et al. 1996).

The price elasticity of supply measures the extent to which relative changes in the price of a good are associated with relative changes in the quantity supplied (Nicholson, 1995). Adelaja (1991) provided price elasticities of milk supply of 0·6785, 0·3815, and 0·7585 for small, medium and large farm size categories respectively. For the price elasticity of supply, this analysis assumed a rectangular distribution, with 0·3815 and 0·7585 set as the lower and upper limits. The rectangular (also known as 'uniform') distribution is recommended when a researcher believes that all values between two limits have the same likelihood, and where the researcher cannot prefer specific values without having more information (Kessel, 2003).

As mentioned above, USDA, APHIS (1997) used data from the Dairy '96 Study to develop a logistic-regression model that identified categorical risk factors (i.e., categorical variables) associated with high levels (>5%) of PDD on US dairy operations (Table 6). Wells et al. (1999) again presented the model and repeated the procedures followed to create the model. Methods similar to those described by Losinger (2006) were used to calculate population-attributable fractions based on the logistic-regression model of USDA, APHIS (1997).

The population-attributable fraction (**PAF**) is a measure of the fraction of disease that could be prevented by eliminating exposure to a specific categorical risk factor from a population, while the distribution of other risk factors in the population remains constant (Rockhill et al. 1998). The basic formula for computing the population-attributable fraction (PAF) is:

$$PAF_i=p_i\left(\frac{e^{\beta_i}-1}{e^{\beta_i}}\right)$$

where PAF_i is the population-attributable fraction, β_i is the coefficient from the logistic-regression model, and p_i is the proportion of cases for the i-th category of a categorical risk factor (Rockhill et al. 1998). The logistic-regression model coefficients, and the associated proportion of operations with high PDD, appear with the standard errors in Table 6. For the base category (i=1), $\beta_1=0$, e^{β_1} equals one, and PAF_1 is zero. For categories other than the base category, PAF_i indicates the fraction of disease that could be prevented by shifting everyone in a particular category to the base category of the risk factor (Rockhill et al. 1998).

Table 3. Uncertainty budget for the change in producer surplus as a result of reduced milk production associated with PDD in US dairy cows in 1996

Input quantity	Sensitivity coefficient	Uncertainty contribution	Index
Reduced milk production in lame dairy cows (kg/cow)	$1{\cdot}6\times10^{6}$	$1{\cdot}8\times10^{8}$	56·5%
Percent of US dairy cows that had PDD in 1996	$3{\cdot}3\times10^{7}$	$2{\cdot}0\times10^{7}$	0·7%
Number of dairy cows	$6{\cdot}0\times10^{1}$	$7{\cdot}3\times10^{6}$	0·0%
Kg milk produced in 1996	$1{\cdot}2\times10^{-5}$	$7{\cdot}7\times10^{3}$	0·0%
Mean price of milk in 1996 ($/kg)	$1{\cdot}7\times10^{9}$	$3{\cdot}7\times10^{6}$	0·0%
Price elasticity of demand for milk	$3{\cdot}0\times10^{9}$	$1{\cdot}5\times10^{8}$	42·7%
Price elasticity of supply for milk	$-1{\cdot}2\times10^{7}$	$-1{\cdot}3\times10^{6}$	0·0%

The final estimate for the change in producer surplus is an increase of $\$5.62\times10^{8}$, with a standard uncertainty of $\$2.37\times10^{8}$ and 76 df. The resulting value and expanded uncertainty, with a coverage factor of two, is then an increase of:

$560 000 000 ± $470 000 000

The combined PAF for a variable with multiple categories is computed by summing PAF_i of the non-base categories:

$$PAF=\sum_{i=2}^{k}PAF_i=\sum_{i=2}^{k}p_i\left(\frac{(e^{\beta_i}-1)}{e^{\beta_i}}\right)$$

(for a categorical variable with k categories). The combined PAF shows the fraction of disease that could be prevented by shifting everyone outside of the risk factor's base category to the base category (while the distribution of other factors in the population remained constant) (Rockhill et al. 1998).

GUM Workbench (Metrodata GmbH, 1999) was applied to compute estimates and uncertainties of PAF for each of the PDD risk factors that had been identified in the model of USDA, APHIS (1997). Unfortunately, neither USDA, APHIS (1997), nor Wells et al. (1999) provided the standard errors for the proportions of cases. As mentioned above, when no better information is available, an educated guess is to be used for the uncertainty of an input quantity (ISO, 1995). Therefore, a conservative estimate of 0·05 was applied for the standard uncertainty for each of the proportions of cases of Table 6. All of the standard uncertainties for the proportions of cases for Losinger's (2006) analysis of Johne's disease risk factors, which came from the same NAHMS Dairy '96 Study, were less than 0·05. It appears unlikely that any of the standard errors associated with the proportions of cases in the present study were much more than 0·05. Economic impacts of specific risk factors for PDD were computed by multiplying all of the terms above by the PAF for the risk factor, as described by Losinger (2006).

Results

Results from the model equations and data entered into GUM Workbench indicated that PDD caused milk production to fall by 570±370 million kg (2-sigma confidence interval). If PDD had not been present on US dairy operations, then milk production would have risen to 70·6±1·3 billion kg, and the market price would have declined to 31·7±0·9 cents/kg. The value of milk production would have fallen from $23.0±0.5 billion to $22.4±0.7 billion. The decline in the value of milk production of $570±480 million is significantly greater than zero ($P<0{\cdot}05$, based on the observation that the 2-sigma confidence interval does not include zero).

Uncertainty budgets, estimates, and expanded uncertainties for the change in consumer surplus, change in producer surplus and total economic loss due to reduced milk production associated with PDD in US dairy cows appear in Tables 2–4. For each input quantity, uncertainty budgets provide the sensitivity coefficient ($\partial y/\partial x_i$), the uncertainty contribution (which is the product of the standard uncertainty and the sensitivity coefficient), and an index which is the percent contribution to the square of the measurand's uncertainty. The index is 100 times the ratio of the square of the input quantity's uncertainty contribution to the square of the uncertainty in the estimated value of the measurand. The indices sum to 100%. The uncertainty budgets demonstrate that the estimate of reduced milk production in dairy cows with PDD contributed towards most of the uncertainty in the estimates. The price elasticity of demand for milk accounted for 29·7% (Table 2) and 42·7% (Table 3) of the uncertainty in the change in consumer and producer surplus, respectively.

The last two columns of Table 5 present PAF and standard errors for each of the risk factors for PDD. PAF suggest, for example, that about two-thirds of high PDD in dairy operations could have been prevented if no cows on the operation had been born outside of the operation, and that nearly one-half of high PDD cases could have been averted by not using hoof trimmers who also trimmed cattle hooves on other operations. Uncertainty budgets provided by GUM Workbench showed that most of the uncertainty in PAF proceeded from the logistic regression

Table 4. Uncertainty budget for the total economic loss resulting from reduced milk production associated with PDD in US dairy cows in 1996

Input quantity	Sensitivity coefficient	Uncertainty contribution	Index
Reduced milk production in lame dairy cows (kg/cow)	$5·5\times10^{5}$	$6·2\times10^{5}$	98·4%
Percent of US dairy cows that had PDD in 1996	$1·1\times10^{7}$	$6·8\times10^{6}$	1·2%
Number of dairy cows	$2·1\times10^{1}$	$2·5\times10^{6}$	0·2%
Kg milk produced in 1996	$-5·6\times10^{-5}$	$-3·5\times10^{4}$	0·0%
Mean price of milk in 1996 ($/kg)	$5·8\times10^{8}$	$1·3\times10^{6}$	0·0%
Price elasticity of demand for milk	$4·8\times10^{7}$	$2·4\times10^{6}$	0·1%
Price elasticity of supply for milk	$1·2\times10^{7}$	$1·3\times10^{6}$	0·0%

The final estimate for the total economic loss resulting from reduced milk production attributed to PDD in US dairy cows is $\$1.92\times10^{8}$, with a standard uncertainty of $\$6.25\times10^{7}$ and 54 df. The resulting value and expanded uncertainty, with a coverage factor of two, is then:

$190 000 000 ± $130 000 000

model coefficients. For many variables, however, the proportions of cases contributed towards >10% of the uncertainties in PAF, possibly because of the rather conservative uncertainties attributed to the proportions of cases. However, this result means that covariances between the logistic-regression model coefficients and the proportions of cases should not be ignored in computing the uncertainty of PAF (Kessel et al. 2001). Since covariances were not available, the standard errors of PAF presented in Table 5 should be regarded as somewhat rough estimates.

Table 6 provides the estimated economic impacts of the specific risk factors for PDD. Impacts of herd size were somewhat marginal. Economic impacts of being in the northeast *v.* the southeast were statistically significant – comparisons for the other regions *v.* the southeast were not. Having access to both pasture and drylot during the winter was not statistically different from having access to pasture only, which indicates that USDA, APHIS (1997) should have turned this variable into a simple dichotomous variable indicating whether or not cows had access to pasture in the winter. In terms of flooring type, moving from grooved concrete to textured concrete would have had a substantial impact: impacts of other flooring types were not statistically significant. Having any cows that were not born on the operation, using hoof trimmers that trimmed hooves on other operations, and not routinely washing hoof-trimming equipment with water between cows, all were accompanied by significant economic impacts.

Tables 7–11 present uncertainty budgets for the total economic impacts of risk factors other than herd size and region. In each case, the estimated reduction in milk production in lame dairy cows accounted for most of the uncertainty in the total economic impact. In addition, the proportions of cases contributed towards <10% of the uncertainties in the economic impacts, which means that covariances between the logistic-regression model coefficients and the proportions of cases can safely be ignored (Kessel et al. 2001). The rationale for only being concerned about covariances between input quantities whose contribution to the variance of the measurand is at least 10% is that ISO (1995) specifically recommends that numerical values of estimates and their uncertainties not be given with an excessive number of digits, usually no more than two. Incorporating covariance estimates for input quantities whose contribution to the variance of the measurand is less than 10% would thus not influence the measurement results.

Discussion

Basic methods for measuring the economic impacts of animal diseases, and of specific epidemiologic risk factors for animal diseases, were described in detail by Losinger (2005a, b), who measured the economic impacts of Johne's disease and of specific epidemiologic risk factors for Johne's disease. The approach is sufficiently straightforward that one could easily apply the same methods to measure the economic impacts of a different animal disease with a new set of risk factors. If one writes a series of similar papers with just a new disease, one may incur the risk of becoming vulnerable to accusations of plagiarism, or even quackery (Losinger, 2003). No-one ever begins research completely from scratch, and it is supremely important for an author to acknowledge the derivative nature of his work, and to delineate exactly where his contribution lies (Vardeman & Morris, 2003). The present paper measures the economic impacts of a different disease (PDD) and a new set of risk factors. In the present study, the proportions of cases (for individual epidemiologic risk factors) contributed towards >10% of the uncertainties in many PAF, which meant that covariances between the logistic-regression model coefficients and the proportions of cases should not have ignored in computing the uncertainty of PAF. Previously, the proportions of cases contributed towards <10% of the uncertainties in PAF for

Table 5. Proportion of US dairy operations with >5% of dairy cows with PDD, logarithms of the odds ratios (i.e., coefficients from the logistic-regression model) and population-attributable fractions, for risk factors identified as being associated with a dairy operation having >5% of dairy cows with PDD

Risk factor	Proportion of operations that had >5% of dairy cows with PDD†	Logistic-regression model†		Population-attributable fraction	
		Coefficient	SE	PAF	SE
Number of dairy cows					
<100	0·64	0·00	—	—	—
100–299	0·23	0·69	0·20	0·11	0·03
⩾300	0·13	0·99	0·25	0·08	0·03
Total	1			0·20	0·05
Region					
Southeast	0·02	0·00	—	—	—
West	0·12	0·53	0·41	0·05	0·04
Midwest	0·52	0·59	0·40	0·23	0·12
Northeast	0·34	1·22	0·41	0·24	0·11
Total	1			0·52	0·14
Land lactating cows access in winter					
Pasture only	0·02	0·00	—	—	—
Both pasture and drylot	0·07	0·69	0·45	0·03	0·03
Neither pasture nor drylot	0·30	0·96	0·44	0·18	0·06
Drylot only	0·62	1·46	0·42	0·47	0·07
Total	1			0·69	0·10
Predominant flooring type on which lactating cows walk					
Textured concrete	0·11	0·00	—	—	—
Dirt/pasture/other	0·10	0·18	0·35	0·02	0·03
Slatted or smooth concrete	0·40	0·59	0·27	0·18	0·06
Grooved concrete	0·39	0·99	0·28	0·25	0·05
Total	1			0·44	0·09
Percent of dairy cows not born on the operation					
0%	0·17	0·00	—	—	—
1–24%	0·44	1·41	0·22	0·33	0·04
25% or more	0·40	2·07	0·25	0·35	0·05
Total	1			0·68	0·07
Hoof trimmer also trims cattle hooves on other operations					
No (or no hoof trimming)	0·25	0·0	—	—	—
Yes	0·75	1·03	0·21	0·48	0·06
Hoof trimming equipment routinely washed with water between cows					
Yes (or no hoof trimming)	0·24	0·0	—	—	—
No	0·76	0·64	0·19	0·36	0·08

† Source: USDA, APHIS, 1997, and Wells et al. 1999

Johne's disease, which meant that the covariances between the logistic-regression model coefficients and the proportions of cases could safely be ignored in computing the uncertainty of PAF for Johne's disease (Losinger, 2006). In the present study, although covariances were not available (and hence the uncertainties of PAF were questionable), the proportions of cases contributed towards <10% of the uncertainties in the economic impacts (Tables 7–11), which meant that, for these estimates, the covariances between the logistic-regression model coefficients and the proportions of cases could safely be ignored. The present study exposes not only the economic impacts of a new disease (PDD) and a new set of risk factors, but also a new and unique situation with respect to the computation of the economic impacts of risk factors for an animal disease.

A limitation of many prior economic-welfare analyses of animal diseases (e.g., Ebel et al. 1992; Forsythe & Corso, 1994; Ott et al. 1999) is that they completely ignored the uncertainty of their estimates. Piggott (2003) used a Monte-Carlo method to compute confidence intervals for estimated welfare effects (for producers) from

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Table 6. Economic impacts of increased milk production associated with removing specific risk factors for PDD from the US population of dairy cows in 1996. The coverage factor is two (i.e., plus or minus twice the standard uncertainty)

	Milk production			Change in economic surplus		
	Quantity ($kg \times 10^9$)	Price (cents/kg)	Total value ($\$ \times 10^9$)	Consumers ($\$ \times 10^6$)	Producers ($\$ \times 10^6$)	Total economy ($\$ \times 10^6$)
1996 Totals†	70·0±1·2	32·8±0·8	23·0±0·5	—	—	—
Total impact of papillomatous digital dermatitis	70·6±1·3*	31·7±0·9*	22·4±0·7*	750±580	−560±470	190±130
Number of dairy cows						
100–299	70·1±1·3*	32·7±0·4*	22·9±0·5	86±84	−64±67	22±19
⩾300	70·1±1·3	32·7±0·4	22·9±0·5	62±70	−46±55	16±16
Total	70·1±1·3*	32·6±0·5*	22·9±0·5*	150±130	−110±110	37±30
Region						
West	70·0±1·3	32·8±0·4	22·9±0·5	37±62	−28±48	9±15
Midwest	70·1±1·3	32·6±0·5	22·8±0·5	170±230	−130±280	43±54
Northeast	70·1±1·3*	32·5±0·5*	22·8±0·5*	180±160	−140±130	45±36
Total	70·3±1·3*	32·2±0·7*	22·7±0·6	390±360	−290±290	96±79
Land lactating cows access in winter						
Both pasture and drylot	70·0±1·3	32·8±0·4	22·9±0·5	26±49	−19±37	6±12
Neither pasture nor drylot	70·1±1·3	32·6±0·5*	22·9±0·5	140±140	−100±110	35±32
Drylot only	70·3±1·3	32·3±0·6*	22·7±0·6*	360±290	−270±240	90±64
Total	70·4±1·3*	32·1±0·7*	22·6±0·6	520±420	−390±350	131±93
Predominant flooring type on which lactating cows walk						
Dirt/pasture/other	70·0±1·3	32·8±0·4	23·0±0·5	12±47	−9±36	3±12
Slatted or smooth concrete	70·1±1·3	32·6±0·5	22·9±0·5	130±140	−100±110	33±33
Grooved concrete	70·1±1·3*	32·5±0·5	22·8±0·5*	190±160	−140±130	47±36
Total	70·3±1·3*	32·3±0·6*	22·7±0·6*	330±290	−250±230	83±64
Percent of dairy cows not born on the operation						
1–24%	70·2±1·3*	32·5±0·5*	22·8±0·5*	250±200	−190±160	62±44
25% or more	70·2±1·3*	32·4±0·5*	22·8±0·5*	260±210	−200±170	66±46
Total	70·4±1·3*	32·1±0·7*	22·6±0·6*	510±410	−380±330	129±87
Hoof trimmer also trims cattle hooves on other operations						
Yes	70·3±1·3*	32·3±0·6*	22·7±0·6*	360±290	−270±240	92±64
Hoof trimming equipment routinely washed with water between cows						
Yes	70·2±1·3*	32·4±0·6*	22·8±0·6	270±240	−200±190	68±54

† From Table 2
* Significant difference ($P<0·05$) from 1996 total

generic advertising of meat, and found that the impact was not significantly different from zero. If measured, one would not be surprised to find the uncertainties associated with measures of economic welfare to be rather large. The present study applies the uncertainty-analysis methods espoused by ISO (1995) to the economic impact of PDD.

A limitation of the present study is that no information was available specifically on the production and on-farm economic impacts of PDD. Estimates of the economic impacts of reduced milk production associated with PDD were made with the best available information, using GUM Workbench to analyse sources of uncertainty. As mentioned by USDA, APHIS (1997), and by Wells et al. (1999), the reporting of PDD depended upon the memory and knowledge of the survey respondents, some of whom may have either forgotten or not recognized occurrences of the disease.

To date, Monte Carlo simulation methods have been more popular to analyse economic and epidemiologic information when direct data are limited. For example, to analyse the benefits and costs of animal identification for disease prevention and control, Disney et al. (2001) applied Monte Carlo simulation techniques to various disease scenarios with various cost assumptions. Schoenbaum & Disney (2003) used Monte Carlo methods to model alternative mitigation strategies for a hypothetical outbreak of foot-and-mouth disease in the USA. Disney & Peters (2003) used Monte Carlo simulation modelling to derive the value of information for risky disease import decisions. An advantage of using some of the software

Table 7. Uncertainty budget for the total economic loss resulting from reduced milk production attributed to PDD associated with dairy cows not having access to pasture during the winter

Input quantity	Sensitivity coefficient	Uncertainty contribution	Index
Reduced milk production in lame dairy cows (kg/cow)	$3{\cdot}8\times10^{5}$	$4{\cdot}2\times10^{7}$	81·8%
Percent of dairy cows with papillomatous digital dermatitis in 1996	$7{\cdot}7\times10^{6}$	$4{\cdot}6\times10^{6}$	1·0%
Number of dairy cows	$1{\cdot}4\times10^{1}$	$1{\cdot}7\times10^{6}$	0·1%
Kg milk produced in 1996	$-2{\cdot}7\times10^{-5}$	$-1{\cdot}7\times10^{4}$	0·0%
Mean price of milk in 1996 ($/kg)	$4{\cdot}0\times10^{8}$	$8{\cdot}6\times10^{5}$	0·0%
Price elasticity of demand for milk	$2{\cdot}2\times10^{7}$	$1{\cdot}1\times10^{6}$	0·0%
Price elasticity of supply for milk	$5{\cdot}8\times10^{6}$	$6{\cdot}4\times10^{5}$	0·0%
Proportion of operations, with >5% PDD, where cows accessed both pasture and drylot in winter	$9{\cdot}7\times10^{7}$	$4{\cdot}8\times10^{6}$	1·1%
Logarithm of the odds ratio for a dairy operation, where dairy cows accessed both pasture and drylot in winter, having >5% PDD†	$6{\cdot}8\times10^{6}$	$3{\cdot}1\times10^{6}$	0·4%
Proportion of operations, with >5% PDD, where cows accessed neither pasture nor drylot in winter	$1{\cdot}2\times10^{8}$	$5{\cdot}9\times10^{6}$	1·6%
Logarithm of the odds ratio for a dairy operation, where dairy cows accessed neither pasture nor drylot in winter, having >5% PDD†	$2{\cdot}2\times10^{7}$	$1{\cdot}0\times10^{7}$	4·9%
Proportion of operations, with >5% PDD, where cows accessed only drylot in winter	$1{\cdot}5\times10^{8}$	$7{\cdot}4\times10^{6}$	2·5%
Logarithm of the odds ratio for a dairy operation, where dairy cows accessed only drylot in winter, having >5% PDD†	$2{\cdot}9\times10^{7}$	$1{\cdot}2\times10^{7}$	6·4%

† These refer to the logistic regression model coefficients of Table 5

Table 8. Uncertainty budget for the total economic loss resulting from reduced milk production attributed to PDD associated with having other than textured concrete as the predominant flooring on which lactating dairy cows walk

Input quantity	Sensitivity coefficient	Uncertainty contribution	Index
Reduced milk production in lame dairy cows (kg/cow)	$2{\cdot}4\times10^{5}$	$2{\cdot}7\times10^{7}$	70·1%
Percent of dairy cows with PDD in 1996	$4{\cdot}9\times10^{6}$	$2{\cdot}9\times10^{6}$	0·8%
Number of dairy cows	9·0	$1{\cdot}1\times10^{6}$	0·1%
Kg milk produced in 1996	$-1{\cdot}1\times10^{-5}$	$-6{\cdot}9\times10^{3}$	0·0%
Mean price of milk in 1996 ($/kg)	$2{\cdot}5\times10^{8}$	$5{\cdot}5\times10^{5}$	0·0%
Price elasticity of demand for milk	$9{\cdot}2\times10^{6}$	$4{\cdot}6\times10^{5}$	0·0%
Price elasticity of supply for milk	$2{\cdot}4\times10^{6}$	$2{\cdot}6\times10^{5}$	0·2%
Proportion of operations, with >5% PDD, where cows walked predominantly on dirt/pasture/other flooring	$3{\cdot}2\times10^{7}$	$1{\cdot}6\times10^{6}$	0·2%
Logarithm of the odds ratio for a dairy operation, where cows walked predominantly on dirt/pasture/other flooring, having >5% PDD	$1{\cdot}6\times10^{7}$	$5{\cdot}7\times10^{6}$	3·2%
Proportion of operations, with >5% PDD, where cows walked predominantly on slatted or smooth concrete	$8{\cdot}5\times10^{7}$	$4{\cdot}2\times10^{6}$	1·8%
Logarithm of the odds ratio for a dairy operation, where cows walked predominantly on slatted or smooth concrete, having >5% PDD	$4{\cdot}3\times10^{7}$	$1{\cdot}2\times10^{7}$	13·8%
Proportion of operations, with >5% PDD, where cows walked predominantly on grooved concrete	$1{\cdot}2\times10^{8}$	$6{\cdot}0\times10^{6}$	3·6%
Logarithm of the odds ratio for a dairy operation, where cows walked predominantly on grooved concrete having >5% PDD	$2{\cdot}8\times10^{7}$	$8{\cdot}0\times10^{6}$	6·3%

Table 9. Uncertainty budget for the total economic loss resulting from reduced milk production attributed to PDD associated with having any dairy cows not born on the operation

Input quantity	Sensitivity coefficient	Uncertainty contribution	Index
Reduced milk production in lame dairy cows (kg/cow)	$3{\cdot}7\times10^{5}$	$4{\cdot}1\times10^{7}$	90·7%
Percent of dairy cows with PDD in 1996	$7{\cdot}6\times10^{6}$	$4{\cdot}6\times10^{6}$	1·1%
Number of dairy cows	$1{\cdot}4\times10^{1}$	$1{\cdot}7\times10^{6}$	0·2%
Kg milk produced in 1996	$-2{\cdot}6\times10^{-5}$	$-1{\cdot}6\times10^{4}$	0·0%
Mean price of milk in 1996 ($/kg)	$3{\cdot}9\times10^{8}$	$8{\cdot}4\times10^{5}$	0·0%
Price elasticity of demand for milk	$2{\cdot}2\times10^{7}$	$1{\cdot}1\times10^{6}$	0·0%
Price elasticity of supply for milk	$5{\cdot}6\times10^{6}$	$6{\cdot}1\times10^{5}$	0·2%
Proportion of operations with >5% PDD where 1–24% of cows were not born on the operation	$1{\cdot}5\times10^{8}$	$7{\cdot}3\times10^{6}$	2·8%
Logarithm of the odds ratio for a dairy operation where 1–24% of cows were not born on the operation having >5% PDD	$2{\cdot}1\times10^{6}$	$4{\cdot}5\times10^{6}$	1·1%
Proportion of operations, with >5% PDD, where ⩾25% of cows were not born on the operation	$1{\cdot}7\times10^{8}$	$8{\cdot}4\times10^{6}$	3·7%
Logarithm of the odds ratio for a dairy operation where ⩾25% of cows were not born on the operation having >5% PDD	$9{\cdot}8\times10^{6}$	$2{\cdot}5\times10^{6}$	0·3%

Table 10. Uncertainty budget for the total economic loss resulting from reduced milk production attributed to PDD associated with having hoof trimmers who also trimmed cattle hooves on other operations

Input quantity	Sensitivity coefficient	Uncertainty contribution	Index
Reduced milk production in lame dairy cows (kg/cow)	$2{\cdot}6\times10^{5}$	$2{\cdot}9\times10^{7}$	83·9%
Percent of dairy cows with PDD in 1996	$5{\cdot}4\times10^{6}$	$3{\cdot}2\times10^{6}$	1·0%
Number of dairy cows	9·9	$1{\cdot}2\times10^{6}$	0·1%
Kg milk produced in 1996	$-1{\cdot}3\times10^{-5}$	$-8{\cdot}3\times10^{3}$	0·0%
Mean price of milk in 1996 ($/kg)	$2{\cdot}8\times10^{8}$	$6{\cdot}0\times10^{5}$	0·0%
Price elasticity of demand for milk	$3{\cdot}1\times10^{6}$	$5{\cdot}6\times10^{5}$	0·0%
Price elasticity of supply for milk	$2{\cdot}9\times10^{6}$	$3{\cdot}1\times10^{5}$	0·0%
Proportion of operations with >5% PDD where hoof trimmers also trimmed cattle hooves on other operations	$1{\cdot}2\times10^{8}$	$6{\cdot}2\times10^{6}$	3·7%
Logarithm of the odds ratio for a dairy operation where hoof trimmers also trimmed cattle hooves on other operations having >5% PDD	$5{\cdot}3\times10^{7}$	$1{\cdot}1\times10^{6}$	11·1%

available for performing Monte Carlo simulations is that researchers have somewhat more flexibility as to the types of statistical distributions they wish to examine. At present, GUM Workbench is limited to symmetrical distributions (i.e., the normal, t, triangular, rectangular, and trapezoidal) (Metrodata GmbH, 1999). The major strength of GUM Workbench, consistent with the recommendations of ISO (1995), is the presentation of the uncertainty budget, which tells an analyst exactly the uncertainty contribution associated with each input quantity. For example, the uncertainty budgets of Tables 2–4 show that the estimate of reduced milk production in dairy cows with PDD contributed towards most of the uncertainty in the estimates. This is consistent with what one would have expected, given the fact that there was considerable uncertainty in the effect of PDD on milk production. The price elasticity of demand for milk was also an important contributing factor towards the uncertainty in the estimates. With Monte Carlo simulations, this type of information is not usually provided as a matter of course.

The present analysis was limited to the economic impacts on primary producers and consumers of reduced milk production associated with PDD. Besides primary producers and consumers, other stakeholders (e.g., feed suppliers, processors, wholesalers, retailers) are involved in the production and distribution of milk. In addition, PDD may be associated with increased veterinary and culling costs for dairy producers, as well as reduced reproductive efficiency in cows. Effects of increased veterinary and culling costs, and of reduced reproductive efficiency, on producer and consumer surplus, are beyond the scope of the present study. More research is warranted

Table 11. Uncertainty budget for the total economic loss resulting from reduced milk production attributed to PDD associated with not routinely washing hoof-trimming equipment with water between cows

Input quantity	Sensitivity coefficient	Uncertainty contribution	Index
Reduced milk production in lame dairy cows (kg/cow)	$1{\cdot}9\times10^{5}$	$2{\cdot}2\times10^{7}$	64·7%
Percent of dairy cows with PDD in 1996	$4{\cdot}0\times10^{6}$	$2{\cdot}4\times10^{6}$	0·8%
Number of dairy cows	7·3	$8{\cdot}9\times10^{5}$	0·1%
Kg milk produced in 1996	$-7{\cdot}2\times10^{-6}$	$-4{\cdot}6\times10^{3}$	0·0%
Mean price of milk in 1996 ($/kg)	$2{\cdot}1\times10^{8}$	$4{\cdot}5\times10^{5}$	0·0%
Price elasticity of demand for milk	$6{\cdot}2\times10^{6}$	$3{\cdot}1\times10^{5}$	0·0%
Price elasticity of supply for milk	$1{\cdot}6\times10^{6}$	$1{\cdot}7\times10^{5}$	0·0%
Proportion of operations, with >5% PDD where hoof-trimming equipment was not routinely washed with water between cows	$9{\cdot}0\times10^{7}$	$4{\cdot}5\times10^{6}$	2·8%
Logarithm of the odds ratio for a dairy operation where hoof-trimming equipment was not routinely washed with water between cows having >5% PDD	$7{\cdot}5\times10^{7}$	$1{\cdot}5\times10^{7}$	31·5%

to examine the economics of PDD beyond producer and consumer surplus changes that resulted from reduced milk production associated with PDD.

Demand for milk tends to be fairly inelastic, meaning that consumers generally purchase a relatively fixed amount of milk over a given time frame, regardless of ordinary price fluctuations (Maynard, 2000), which means that consumers would tend to be the primary beneficiaries of improved milk production. Reduced producer surplus associated with PDD does not mean that dairy producers should be indifferent towards this disease in their dairy cows. An analysis of aggregate welfare impacts will not be a useful decision aid for individual producers. Economic-welfare analyses would be useful primarily to policy makers, who are required to possess a thorough understanding of the implications of various public decisions. For planning purposes, however, dairy producers would find knowledge of the potential price impacts of policy decisions to be extremely useful.

Another limitation of this study is that the risk-factor analysis portion was based upon herds classified as high (>5%) *v.* low incidence of PDD, and this result was applied to the population of dairy cows. Unfortunately, no better national-level analysis of risk factors for PDD was available. An animal-level risk-factor analysis, similar to that performed, for example, by Losinger et al. (2000) on early-postnatal mortality of US foals, would have been ideal for an economic analysis of risk factors for this disease. Losinger et al. (2000) created a data file that consisted of one observation for each newborn foal, and performed an economic analysis of the expected costs of testing for adequate absorption of colostral immunoglobulins. Researchers who deal with data from second-hand sources often must make do with data inputs that are less than ideal. Researchers who do have access to primary data sometimes take shortcuts as well. For example, Ott et al. (1999) developed a herd-level (rather than an animal-level) model to study the economic impacts of Johne's disease, and then multiplied by the number of dairy cows in the country to estimate national impacts, without first modifying the sample weights to reflect the number of dairy cows (rather than the number of dairy operations) that each survey participant represented.

Wells et al. (1999) previously provided combined PAF for the risk-factor variables listed in Table 6, but did not provide PAF for the individual categories of the multi-category variables. Wells et al. (1999) used the formula for combined PAF that was initially developed by Bruzzi et al. (1985), and in which Losinger (2006) identified some flaws. To compute confidence intervals for combined PAF, Wells et al. (1999) substituted the lower and upper bounds of the confidence intervals for the odds ratios from the logistic-regression model into the formula for combined PAF. Siskind et al. (2002) used the same procedure, which they justified by asserting that the contribution of the percent of cases to the uncertainty in the estimate of PAF was negligible compared with the contribution to the PAF's uncertainty from the logistic-regression-model coefficients. Uncertainty budgets for combined PAF demonstrate that, in this particular instance, the contributions from the percent of cases to the uncertainties in the estimates of PAF were not negligible. Therefore, the procedures used by Wells et al. (1999) to compute the confidence intervals for combined PAF were not correct, and were quite a bit wider than confidence intervals that would derive from the Table 5. As mentioned in the results section, these uncertainties should be regarded as rough estimates, as covariances between the logistic-regression model coefficients and the proportions of cases were not available. However, as also mentioned in the Results section, Tables 7–11 show that the proportions of cases contributed towards <10% of the uncertainties in the economic impacts, which means that the covariances between the logistic-regression model coefficients and the proportions of cases can safely be ignored in the estimation of the uncertainties of the economic impacts of the risk factors.

Table 5 suggests that the type of land to which lactating cows had access in the winter conferred the greatest risks for PDD, and Table 6 confirms that this risk factor had the greatest economic impact. Specifically, the tables show that if pasture were the only type of land to which dairy cows had access, then nearly 70% of cases might have been averted, with a total saving of $131 million to the US economy. However, putting all cows on pasture would have many effects not accounted for in this study. For example, cooling in the summer (particularly in the Southern states) may be more difficult on pasture (particularly if no shade is available), which would result in a loss of milk production. Thus although this study suggests that elimination of certain risk factors for PDD might increase milk production, alternative management strategies could be costly. These costs are not accounted for in this study. A production-function type of analysis would be required to help individual producers to make production decisions (Debertin, 1986). For example, NAHMS data were used to develop a catfish production function, which served to identify stages of production and profit-maximizing rates of input application (Losinger et al. 2000). A production-function type of analysis, which requires access to raw production data, would be very useful to examine whether it is profitable for an individual producer to control PDD and to what extent. It could well be that most producers are controlling PDD to the level that is economically feasible for them. An analysis of aggregate welfare impacts will not capture this.

Dairy producers should not take the results of this study to mean that they, individually, are better off with PDD on their farms. Rather, at the industry level, the increased price (due to reduced milk production associated with PDD) makes producers, as a whole, better off. Most people connected to the US dairy industry know that dairy prices can be rather volatile. At the macroeconomic level, how to transfer benefits from consumers to producers, to provide producers with the incentive to control a disease, represents a classic economic puzzle for which the solution is not obvious.

In terms of predominant flooring type, textured concrete appeared to be preferable to smooth concrete (in terms of reducing risk of PDD). Economic impacts associated with other predominant flooring types were not significantly different from textured concrete (Table 6).

Having dairy cows that were not born on the operation presented a great risk for PDD (Table 5), and also generated substantial cost associated with the disease (Table 6). Whether the percent of cows not born on the operation was between 1% and 25%, or >25%, seemed to make little difference. Moving either category to 0% would have reduced the prevalence of high levels of PDD by about one-third (Table 6). Moving both categories to 0% would have saved the economy about $130 million, which is almost double the economic costs of this same risk factor associated with Johne's disease (Losinger, 2006). Thus, from the standpoint of both Johne's disease and PDD, dairy producers have a strong incentive to be especially vigilant about sources of new dairy cows. Sometimes, dairy producers may need to introduce new cows from outside the operation and, when they do, they should make an effort to verify that the source of new dairy cattle is free of both PDD and Johne's disease.

USDA, APHIS (1997) and Wells et al. (1999) described washing hoof trimming equipment between cows, and using hoof trimmers who trimmed cattle hooves on other operations, as 'biosecurity concerns'. However, it would probably be quite erroneous to use the results of this study to conclude that not using hoof trimmers who trimmed cattle hooves on other operations would have saved the economy $\$92 \pm 64$ million (Table 6). I presume that most hoof trimmers are quite professional, and are careful not to transfer hoof diseases from one farm to another. Unfortunately, the NAHMS Dairy '96 Study did not probe more deeply into specific practices of hoof trimmers who trimmed cattle hooves on other operations, nor into whether the professional hoof trimmers were hired because of specific problems (USDA, APHIS, 1997). An epidemiological study might identify a link between headaches and the taking of aspirin. However, it would be wrong to conclude that taking aspirin caused headaches, if most people took the aspirin after the headache appeared (for the purpose of treating the headache). Similarly, it is probably wrong to blame hoof trimmers for increased PDD, especially when many of the hoof trimmers may have been hired specifically to treat the disease. Nonetheless, the findings of USDA, APHIS (1997) and of Wells et al. (1999) do generate interesting hypotheses for further study.

PDD is a disease affecting dairy cows that is very costly to the US economy. Results of this study indicated that PDD caused milk production to fall by 570 ± 370 million kg, the market price to rise by $1{\cdot}1 \pm 0{\cdot}8$ cents/kg and the total value of the milk produced to increase by $\$570 \pm 480$ million in 1996. Although the US dairy industry, as a whole, experienced an economic gain due to the reduced milk production (and higher milk prices) associated with the disease, this study did not address the treatment and other costs that individual dairy producers may face when confronted with this disease. Economic impacts of specific risk factors for the disease could be valuable in assessing the potential benefits of mitigation strategies designed to reduce PDD in dairy cows.

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