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Bayesian evaluation of budgets for endemic disease control: An example using management changes to reduce milk somatic cell count early in the first lactation of Irish dairy cows

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ABSTRACT

The aim of this research was to determine budgets for specific management interventions to control heifer mastitis in Irish dairy herds as an example of evidence synthesis and 1-step Bayesian micro-simulation in a veterinary context. Budgets were determined for different decision makers based on their willingness to pay. Reducing the prevalence of heifers with a high milk somatic cell count (SCC) early in the first lactation could be achieved through herd level management interventions for pre- and peri-partum heifers, however the cost effectiveness of these interventions is unknown. A synthesis of multiple sources of evidence, accounting for variability and uncertainty in the available data is invaluable to inform decision makers around likely economic outcomes of investing in disease control measures. One analytical approach to this is Bayesian micro-simulation, where the trajectory of different individuals undergoing specific interventions is simulated. The classic micro-simulation framework was extended to encompass synthesis of evidence from 2 separate statistical models and previous research, with the outcome for an individual cow or herd assessed in terms of changes in lifetime milk yield, disposal risk, and likely financial returns conditional on the interventions being simultaneously applied. The 3 interventions tested were storage of bedding inside, decreasing transition yard stocking density, and spreading of bedding evenly in the calving area. Budgets for the interventions were determined based on the minimum expected return on investment, and the probability of the desired outcome. Budgets for interventions to control heifer mastitis were highly dependent on the decision maker's willingness to pay, and hence minimum expected return on investment. Understanding the requirements of decision makers and their rational spending limits would be useful for the development of specific interventions for particular farms to control heifer mastitis, and other endemic diseases.

1. Introduction

For 50% of Irish dairy herds, reducing the prevalence of heifers with high milk somatic cell count (SCC) between 5 and 30 days in milk (DIM) would be associated with savings through increased longevity, and lifetime milk yield (Archer et al., 2013a, b). A reduction in the prevalence of heifers with high SCC early in lactation could be achieved through herd level management interventions targeted at

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pre- and *peri-partum* (ppp) heifers (Green et al., 2008). Previous studies have identified risk factors for mastitis in heifers (De Vliegher et al., 2012), however the cost and efficacy of particular management changes have yet to be evaluated in the field. Data on the likely cost effectiveness of management interventions is therefore unavailable. However, potentially effective interventions may not be deemed to be 'cost effective' if they are too expensive to implement, or the desirable outcome is too uncertain for particular decision makers (Spiegelhalter et al., 2004). It is therefore unrealistic for economic analyses to assume an unlimited 'willingness to pay' for each Euro saved through reduced disease costs, however rational budgets for management interventions are unknown. This information would facilitate the development of practical advice to control heifer mastitis on Irish dairy farms.

Uncertainty and variability in parameters can be handled with a Bayesian analyses, in which prior knowledge is combined with data obtained from a particular study to generate posterior probability distributions for outcomes that represent the updated state of knowledge, and are inherently useful for decision makers (Spiegelhalter et al., 2004; Bolstad, 2007). As a further aid to decision making, the Bayesian approach can be extended by using micro-simulation to generate posterior predictions for particular scenarios that require clear interpretation (Parmigiani, 2002). The trajectory of individuals is modelled as if a carefully controlled trial were conducted, varying only the exposure of interest. This approach is useful when such a trial would be impossible or very expensive (Archer et al., 2013a, b). Making distributional assumptions can be avoided, and all uncertainty and relationships between variables can be propagated through to the final outcome by using a 1-step procedure (Chessa et al., 1999; Spiegelhalter et al., 2004). A 2-step micro-simulation procedure, where distributions for parameters are obtained from other research and expert opinion is more common, and has been used to estimate the cost of high SCC shortly after calving in heifers (Huijps et al., 2009a). The integrated 1-step procedure has been applied to investigate the impact of management interventions in dairy herds, with iterations propagated from a single model (Green et al., 2010). However, the approach can be extended to synthesise evidence from multiple sources, as used in cost effectiveness analyses for human medical treatments (O'Hagan and Stevens, 2001; Spiegelhalter and Best, 2003). To our knowledge this method has not been applied in a veterinary context. As an example of its application, the aim of this research was to use 1-step Bayesian micro-simulation to synthesise evidence and determine budgets for specific management interventions to control heifer mastitis in Irish dairy herds under different circumstances.

2. Materials and methods

2.1. Overview

A micro-simulation was used for a partial budget analysis to estimate the likely economic impact of specific interventions to reduce SCC in Irish dairy heifers between 5 and 30 DIM (SCC1) in terms of change in lifetime milk yield and cow disposal risk (Fig. 1). Lifetime milk yield is determined by survival time and milk yield while alive. Cow disposal risk was used to determine replacement costs where culling occurred. The impact of management interventions reported to reduce SCC1 was modelled using the simulation. Potential financial savings associated with applying the interventions were estimated from the mean difference in lifetime milk yield, and disposal risk at herd level with and without the interventions being applied. The probability of cost effectiveness, and maximum rational spend for implementing these management interventions was estimated for different decision makers based on their willingness to pay.

2.2. Lifetime milk yield model (Model 1)

This model evaluated the association between the SCC1, and lifetime milk yield over 5 to 8 years for heifers in Irish dairy herds (Archer et al., 2013a). The dataset included records from 53,652 heifers in 5922 Irish herds. This was split into 2 samples of 2328, and 3594 herds at random. A linear model with lifetime milk yield as the outcome, and a random effect to account for variation between herds, was fitted to the data for the first sample of herds; data for the second sample was used for cross validation. The model was developed in a Bayesian framework using WinBUGS 1.4.3 (Lunn et al., 2000) and took the form;

$$y_{ij} = \alpha + \mathbf{X_{ij}}\boldsymbol{\beta_1} + \mathbf{X_j}\boldsymbol{\beta_2} + u_j + e_{ij},$$

$$u_j \sim \text{Normal}(0, \sigma_u^2),$$

$$e_{ij} \sim \text{Normal}(0, \sigma_e^2),$$

where y_{ij} = lifetime milk yield for the ith cow in the jth herd, α = intercept value, $\mathbf{X_{ij}}$ = matrix of exposure variables for each cow, $\boldsymbol{\beta_1}$ = vector of coefficients for $\mathbf{X_{ij}}$, $\mathbf{X_j}$ = matrix of exposure variables for each herd, $\boldsymbol{\beta_2}$ = vector of coefficients for $\mathbf{X_j}$, u_j = a random effect to account for residual variation between herds, and e_{ij} = residual level 1 error. Parameters were estimated from 10,000 Markov chain Monte Carlo (MCMC) iterations, following a burn in of 1000 simulations during which time chain convergence occurred. Vague prior distributions were used for; $\sigma_u^{-2} \sim \text{Gamma}(0.001, \quad 0.001)$, $\sigma_e^{-2} \sim \text{Gamma}(0.001, \quad 0.001)$, and $\boldsymbol{\beta} \sim \text{Normal}\ (0, 10^6)$, to give the major influence to the data in the estimation of parameters (Green et al., 2004). To focus attention on the ppp period for the control of heifer mastitis, only confounding variables deemed to be operating by 30 DIM, such as month of first calving and DIM at the first recording were investigated for inclusion. The model was a good fit to the data, and performed well in cross validation. The coefficients from this model directly fed into the micro-simulation are summarised in Table 1. Overall, one unit increase in the natural logarithm of (ln) SCC1 was associated with a median decrease in lifetime milk yield of 865 (95% Bayesian credibility interval (CI) 702 to 1025) kg.