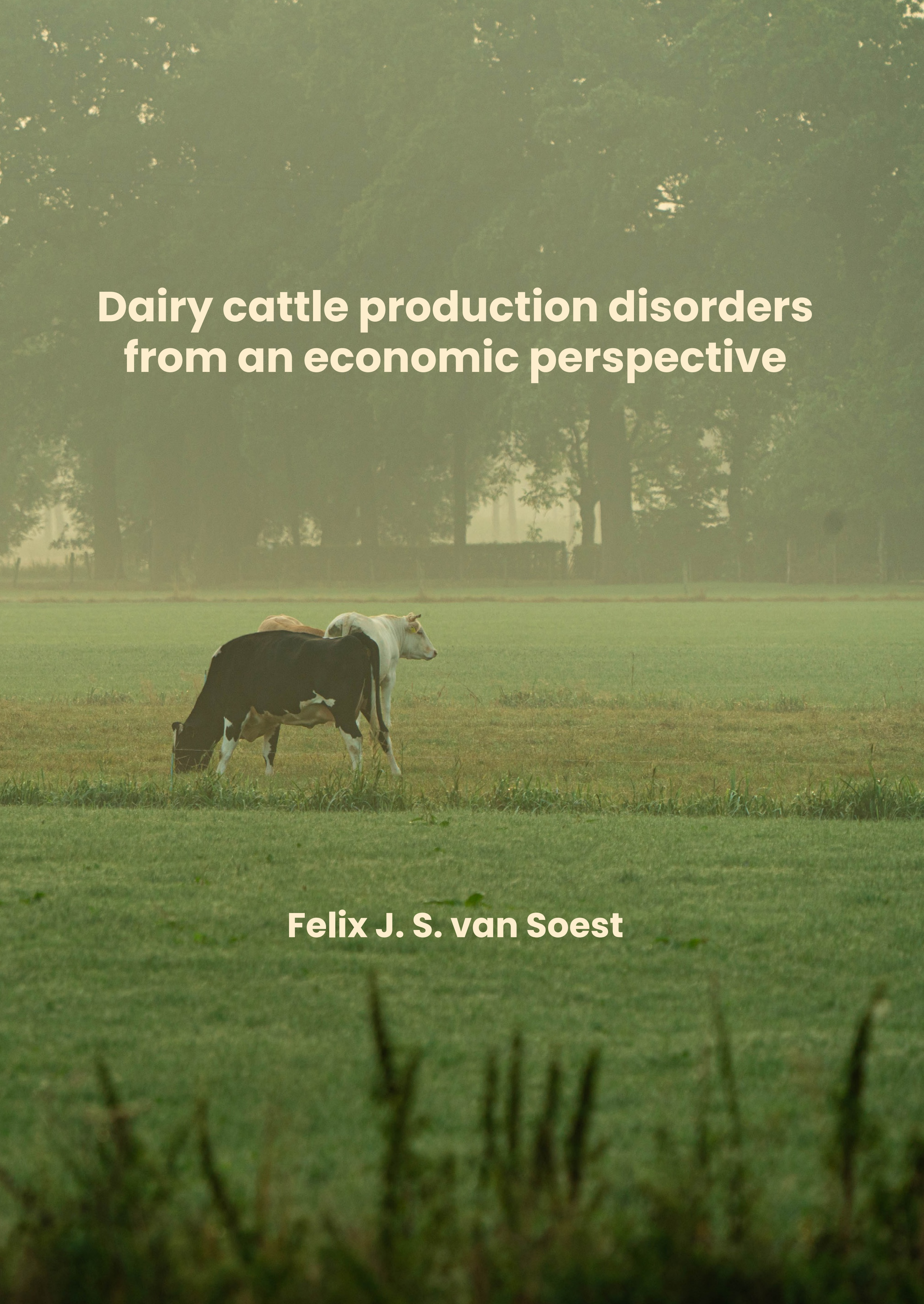
Dairy cattle production disorders from an economic perspective



Felix J. S. van Soest

Propositions

1. Animal health advisors require economic training to provide tailored advice to the individual farmer
   (this thesis)

2. Personal preferences that influence farmers' decisions on animal health are underexplored
   (this thesis)

3. The demand for novel insights in science leads to the incompatibility of studies

4. Disclosing peer-review committees negatively impacts the objectivity of the review process

5. Agriculture is vital for nature preservation

6. Future pandemic strategies require economic thinking

Propositions belonging to the thesis, entitled

Dairy cattle production disorders from an economic perspective

Felix J. S. Van Soest
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Dairy cattle production disorders from an economic perspective

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Dairy cattle production disorders from an economic perspective

Felix J. S. van Soest

Thesis

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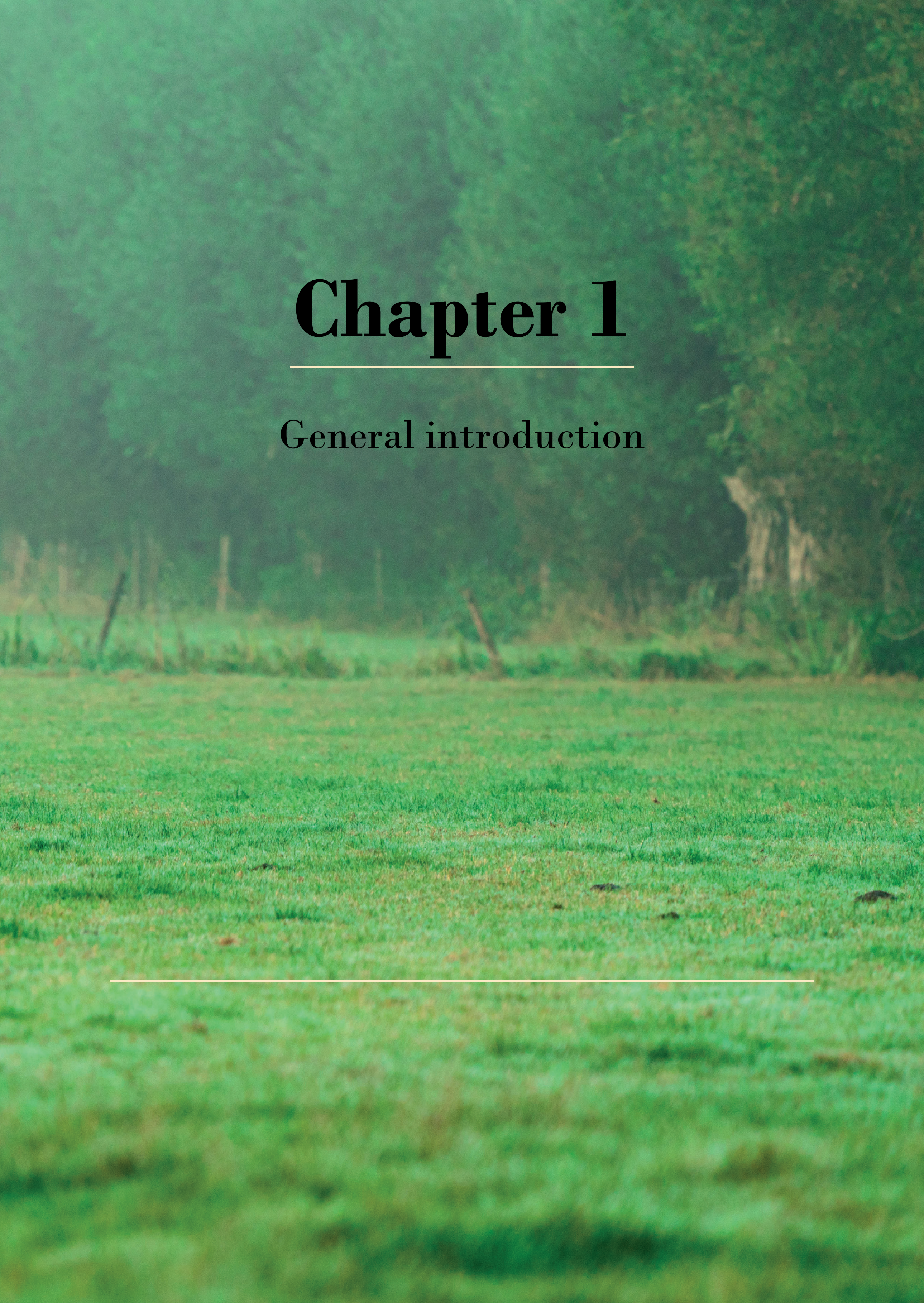

Chapter 1

General introduction

1. INTRODUCTION

Dairy farmers are under increasing pressure from society to produce healthy food coming from healthy animals kept under outstanding conditions (Schleenbecker and Hamm, 2013). Over the years this increased societal concern has led to changes in farmers' attitudes and goals towards animal health and welfare. (Balzani and Hanlon, 2020; Kuipers et al., 2021). Nevertheless, the occurrence of production disorders in dairy cattle has not significantly improved over the last decade (Hovi et al., 2003; Daros et al., 2020; Eriksson et al., 2020; Cruz et al., 2021). Animal health management is part of the overall management of the farm. Resources (i.e., time, labour, land, raw materials and finances) are limited and once spent cannot be reallocated to other areas of management. Farmers need to decide how much of their resources are to be allocated in animal health related activities. This dissertation aims to support individual farmers' decision-making regarding production disorders in dairy cattle, from an economic perspective. Production disorders on dairy farms are defined as animal diseases or health states which are directly linked or impacted by to the production of milk and negatively impact animal performance and/or farm profitability (Halasa et al., 2009b; Hogeveen et al., 2019). Although there are many production disorders that affect farm income the most relevant production disorders to further study, based on a combination of incidence, economic impact and severity, are: mastitis, lameness, ketosis and metritis.

In the following paragraphs these production disorders are described in detail, followed by a description of the currently existing economic knowledge gaps that limit the on-farm decision process for these production disorders. Thereafter the problem statement and associated research objectives are presented. In the final paragraph the general outline of this dissertation is given.

2. PRODUCTION DISORDERS

Four production disorders have been selected for my dissertation. The following sections discuss the definition, occurrence, performance impact and economic impact of each production disorder.

MASTITIS

Definition. Mastitis is an inflammation of the udder and can be subdivided in a clinical and subclinical form. Clinical mastitis is defined as a cow with visual abnormalities in the milk and/ or quarter (Hammer et al., 2012). Whereas subclinical mastitis is an udder inflammation without clinical signs and is often diagnosed based on somatic cell count in the milk. Various thresholds for somatic cell count have been proposed to diagnose subclinical mastitis, i.e. 100,000/ 150,000 cells/ ml (Pyörälä, 2003), 200,000 cells/ ml (Schukken et al., 2003) or 250,000 cells/ml (Dohoo and Meek, 1982).

Occurrence. Clinical mastitis has been reported at an incidence rate of 28.1/ 100 cow-years at risk by Lam et al. (2013) using data of 175 Dutch dairy farms. According to Zwald et al. (2004) most cases of clinical mastitis occur within the first 30 days of lactation, with a prevalence of 23% during this period. In contrast, Suthar et al (2013) found only 6.1% of clinical mastitis cases to occur within the first 30 days in milk. In Sweden, organic dairy cows had a lower average incidence rate of 9.1/ 100 cow-years of veterinary treated clinical mastitis compared to conventional dairy herds with an incidence rate of 14.7/ 100 cows years (Hamilton et al., 2006). For subclinical mastitis in Dutch dairy herds, incidence rates per 100 cow-years at-risk, with a cut-off somatic cell count value of 200,000 cells/mL, were reported at an average of 23.0 (95% confidence interval, 22.2 - 23.9) in 2004 and 22.2 (21.4 - 23.2) in 2009 (van den Borne et al., 2010; Lam et al., 2013).

Production impact. Reviews that summarized estimates of milk production loss associated with clinical mastitis gave an average production loss of 4% and 6% at the lactation level (Hortet and Seegers, 1998; Gro et al., 1999). Subclinical mastitis associated milk loss already occur when the somatic cell count level exceeds 50,000 cells/mL (Dürr et al., 2008; Halasa et al., 2009b). Mastitis cannot be considered as the single predisposing factor reducing fertility as this impact is most likely multifactorial in nature and intertwined with occurrence of other production disorders. Studies therefore report the impact of mastitis on fertility ranges from no impact (Fourichon et al., 2000), a weak impact (Pryce et al., 2004) to a clear impact (Chebel et al., 2004; Huszenicza et al., 2005; McDougall et al., 2016). Mastitis can be seen as one of the most important reasons for on farm culling ranging from 7.8% to 30.7% of all culled animals (Beaudeau et al., 2000; Zwald et al., 2004; Bar et al., 2008; Ahlman et al., 2011).

Economic impact. The economic impact of mastitis is substantial and has been studied by many researchers over the past decades. Hogeveen et al. (2019) gave an overview of the research findings on costs of mastitis up to 2019 indicating an impact varying between €55 and €318/ average cow kept under North European and North American production conditions. Heikilä et al. (2012b) estimated the average costs of mastitis at €147/ cow per yr. Liang et al. (Liang et al., 2017) estimated the economic impact of clinical mastitis at €326 and €427/ case respectively for primiparous and multiparous cows. Most studies nowadays put more emphasis on specific cases of mastitis or focus on treatment strategies and their economic benefit. For instance, Huijps et al. (2009) estimated the costs of (sub)clinical heifer mastitis at €31/ heifer per year and Cha et al. (2011) estimated the costs of gram positive, gram negative and other mastitis causing pathogens, at €123, €193, and €87/ case, respectively. These findings clearly show that mastitis, combined with high prevalence levels, can be detrimental to farm income.

KETOSIS

Definition. Similar to mastitis, ketosis can be divided in a clinical and subclinical form. Clinical ketosis is diagnosed when cattle show decreased appetite, decreased body condition in combination with a decreased milk production. Some cows showing short periods of bizarre neurological and behavioural abnormality (David Baird, 1982; Berge and Vertenten, 2014). Subclinical ketosis is diagnosed by measuring ketones in milk, blood or urine and is defined as an abnormal concentration of circulating ketone bodies in the absence of clinical signs of ketosis (Abutarbush, 2010; van der Drift et al., 2012). Both forms are a consequence of a disturbed energy balance during and/or after calving, where energy intake is insufficient to keep up with the animal's energy demand for milk production.

Occurrence. More than mastitis, ketosis is a disease occurring primarily during the first week's post-partum. Vanholder et al. (2015) reported a prevalence of 47.2% and 11.2% for subclinical ketosis and clinical ketosis, respectively, between 7 – 14 days post-partum. Typically, in scientific literature, ketosis may include both forms, subclinical and clinical (Cainzos et al., 2022). Different methods of diagnosing for subclinical ketosis have been reported in which the golden standard, currently, is measuring plasma β-hydroxybutyrate to indicate the amount of circulating ketone bodies (Duffield, 2000). The observed prevalence of subclinical ketosis in Dutch dairy cows between 5 - 60 days post-partum, at a plasma β-hydroxybutyrate level ≥1,200 μmol/L, was 11.2% (van der Drift et al., 2012). Reported prevalence levels for different production stages were 14.1%, 5.3%, 3.2% and 1.6% for, respectively, early lactation (<65 post-partum), mid lactation (65 – 149 post-partum), late lactation (>149 post-partum) and dry period (Duffield et al., 1997). More recently McArt (2012) reported a peak incidence of 22.3% at 5 days post-partum for subclinical ketosis. Suthar et al. (2013) found an average prevalence of 21.8% for subclinical ketosis during 2 - 15 days post-partum and 3.7% for clinical ketosis.

Production impact. Due to variations in definition of clinical ketosis, mentioned as ketosis, it is not always clear which form of ketosis is meant, in this overview we therefore focus on milk production losses linked to increased β-hydroxybutyrate levels indicating subclinical ketosis. Milk production loss due to subclinical ketosis has been reported at an average

0.5 kg/day during the first 30 days post-partum (McArt et al., 2012), whereas Raboisson et al (2014) reported a higher loss of 112 kg during a 305-day production period. Other studies reported similar production loss values (Duffield et al., 2009; Vanholder et al., 2015). Subclinical ketosis is primarily a disorder of the early-lactation period and intertwined with other condition problems and production disorders. Therefore, effects on fertility may be confounded with these other factors as well. Subclinical ketosis reduced probability of conception by 20% in the first two weeks post-partum and fertility parameters returned to normal after 160 days post-partum, which is a very long period and leaves affected cows susceptible for culling (Rajala and Gröhn, 1998; Walsh et al., 2007; Roberts et al., 2012).

Economic impact. Clinical ketosis is reported to be the costliest form of ketosis and economic impact varies between €64 – €1196 / case of clinical ketosis averaging at €709/ case of clinical ketosis (Steeneveld et al., 2020). Clinical ketosis was estimated to impact primiparous less than multiparous cows, respectively, $77 / case versus $180.91 / case (Liang et al., 2017). Whereas estimated costs of subclinical ketosis varied from US$78 to US$289/ case of ketosis (Geishauser et al., 2001; Guard, 2008; McArt et al., 2015; Steeneveld et al., 2020). The majority of studies on ketosis included costs of other production disorders as well, as ketosis was found to be a predisposing factor for multiple other disorders (McArt et al., 2015; Gohary, 2016; Mostert et al., 2017). For example, in a study performed by Gohary et al. (2016) cost of one case of ketosis was estimated at $203 of which $76 was due to increased costs of other disorders. According to Mostert et al. (2017), cows which contracted only subclinical ketosis had an economic impact of €36/ case per yr. Based on the most recent scientific literature subclinical ketosis, as a single production disorder, does not seem to impact farm income as much as mastitis, however taking into account the predisposing effect ketosis has on contracting other production disorders the impact on farm income can be substantial.

LAMENESS

Definition. Lameness is the result of a group of hoof disorders, that may be non-infectious (e.g., sole haemorrhage, overgrown claws, white line disease and sole ulcer), infectious (digital dermatitis) or a result of physical injuries (e.g. lesions to the claws, joints or bones) (O'Connor et al., 2019). In all scenarios the locomotion apparatus of the cow is affected, in research there seems to be however, more focus on disorders affecting the claw (e.g., dermatitis, white line disease, phlegmon). A commonly accepted method to define the lameness severity is based on locomotion scoring (Whay et al., 1997; Thomsen et al., 2008). Most of these scoring systems use a 5-point ordinal scale (Sprecher et al., 1997; Winckler and Willen, 2001; Flower and Weary, 2006). These five points represent mobility from normal mobility (score 1) to severe lameness (score 5). Nevertheless, as O'Connor (2019) points out different values reflect different forms of mobility but different evaluation methods do not have comparable evaluation scores.

Occurrence. Prevalence of at least one claw disorder at the time of hoof trimming was reported to be more than 70% (Somers et al., 2003; van der Waaij et al., 2005). A recent study by O'Connor reported the prevalence of non-infectious claw disorders to be 85%. In this study sole haemorrhage was most prevalent followed by overgrown claws, white line disease and sole ulcer. Somers et al. (2003) van der Waaij et al. (2005) and Van der Linde et al. (2010) found the same predominant lesions. A study by Manske et al. (2002) on Swedish dairy cows found sole haemorrhage, heel horn erosion and dermatitis to be most prevalent.

Production impact. Production loss for lameness was on average 360 kg/lactation and was reportedly higher for multiparous cows than primiparous cows (Warnick et al., 2001; Green et al., 2002). Whereas O'Connor (2019) reported mild lameness reduces milk production with 102 kg / 305-day milk yield and severe lameness reduces milk yield by 298 kg milk / 305-day milk yield. Lame cows were found to lie down longer and to spend less time standing, walking and expressing oestrus behaviour (Walker et al., 2008). Cows experiencing lameness were less likely to conceive than non-lame cows (Melendez et al., 2003) and conception was found to be delayed by an average of 4-12 days (Alawneh et al., 2011; O'Connor et al., 2019). Barkema et al. (1994) found no effect of lameness on the pregnancy rate at first service. Culling for lameness reasons (including leg problems) was relatively low varying between 2.5 – 5 % of all culled cows (Seegers et al., 1998; Ahlman et al., 2011).

Economic impact. Costs of lameness were estimated at an average of $216, $133 and $121/ case of sole ulcer, digital dermatitis and foot rot, respectively (Cha et al., 2010). Total costs of different lameness causing foot disorders were estimated for an average herd at $479, $825, $1,517, $641/ yr. for, respectively, interdigital phlegmon, interdigital dermatitis and heel erosion, digital dermatitis and sole ulcer (Bruijnis et al., 2010). Estimations on the costs of lameness were generally based on the underlying lameness causing disorder and varied substantially depending on the cause. Two studies so-far estimated the general economic impact of cows moving lame and estimated the costs at US$185 - US$333/ case under US conditions (Liang et al., 2017) and €122/ cow per year under Dutch conditions (Edwardes et al., 2022)

METRITIS

Definition. Metritis can be defined as an inflammation of the reproductive tract and can be caused by pathogenic bacteria such as Escherichia coli, Fusobacterium necrophorum and Prevotella species (Sheldon et al., 2020). For the purpose of this dissertation only the two most common forms are provided: early-metritis and late-metritis. Late-metritis can be further divided in a clinical and subclinical form. Early-metritis occurs within 21 days post-partum and is characterized by an enlarged uterus and a watery red-brown fluid to viscous off-white purulent discharge, which often has a fetid odour (Sheldon et al., 2009). Clinical late-metritis is defined as the presence of a purulent uterine discharge detectable in the vagina ≥21 days post-partum or mucopurulent discharge detectable in the vagina 26 days post-partum (Sheldon et al., 2009). Subclinical late-metritis is characterized by inflammation of the endometrium that results in a significant reduction in reproductive performance in the absence of signs of clinical late-metritis (Sheldon et al., 2009).

Occurrence. Prevalence of metritis was reported at a highly variable rate of 2.7% - 35.7% (Dubuc et al., 2010; Ospina et al., 2010; Chapinal et al., 2011). Variation of prevalence levels may be caused by different definitions for metritis (detection until < 15 days post-partum or < 21 days post-partum).

Production impact. Metritis reduced overall milk production by 129 - 411 kg milk over a 305-day production period (Wittrock et al., 2011; Giuliodori et al., 2013; Mahnani et al., 2015; Carvalho et al., 2019) and decreased feed intake with 1.8 kg / day (Bareille et al., 2003; Wittrock et al., 2011). McCarthy and Overton (2018) observed that poor recording or inconsistent case definition underestimated true milk yield losses due to metritis (clinical and mild cases). Specifically clinical early-metritis reduced milk yield with 847 kg milk during lactation and mild cases of early-metritis reduced milk yield with 384 kg milk / lactation. Although it is clear that metritis affects milk yield, the absolute impact on milk yield between the various forms of metritis remains inconclusive. Much as ketosis metritis is a disorder closely linked to the post-partum period and fertility effects may be confounded by occurrence of multiple production disorders, Nevertheless, fertility was reduced by metritis (Potter et al., 2010; Giuliodori et al., 2013; Mahnani et al., 2015) leading to more open days, 16 days, reduced conception rate, 20%, and increased calving to conception interval, 30 days.

Economic impact. Historically no studies have focused on estimating the costs of metritis, recently a few studies were published. Mahnani et al. (2015) estimated the costs of metritis for four Iranian dairy herds at an average of $162 / case of metritis, costs on individual farms varied from $146 - $176 /

case of metritis. In that study highest costs were attributed to discarded milk and reduced fertility. Liang et al. (2017) estimated the costs for a case of metritis for primiparous cows at US$162 and for multiparous cows at US$263. Highest costs were attributed to discarded milk in both multiparous and primiparous cows. Cost associated with reduced fertility was higher for multiparous cows than primiparous cows.

3. PROBLEM STATEMENT

From the overview provided for the production disorders, it becomes clear that each affects a substantial proportion of dairy cows on a farm and has the potential to incur significant losses to farm income. The economic consequences that are directly associated with the occurrence of a production disorder (e.g., milk production loss, medication, herd removal) are what I call the failure costs. Whereas the costs made to prevent or reduce occurrence of the production disorder (e.g., preventive measures) are what I call the preventive costs.

Much research has been and is still being done with a focus on only the failure costs of a single production disorder. These failure costs are almost always reported in comparison with a situation in which the production disorder is not occurring (Dahl et al., 2018; Pérez-Báez et al., 2021; Puerto et al., 2021). In this way, the total economic impact of the disease is projected. However, all farmers do apply more or less preventive measures. There are costs associated with these preventive measures and these costs are often not accounted for in the published costs of production disorder estimates. There is a hypothesized economic trade-off between failure and preventive costs. A notion that was first introduced by McInerney et al. (1992) and later adapted more specifically to production disorders by Hogeveen et al. (2011). The basic idea of the substitution relationship between failure costs and preventive costs is that an increase in preventive costs leads to diminishing marginal returns (reduced failure costs). Although this hypothesis has not been proven so far (Yalcin et al., 1999), it would imply that there is a rational investment point at which the sum of the failure costs and the preventive costs is minimized, allowing for a cost optimization. To increase decision support on production disorders from an economic perspective, such insights are valuable as it focuses on which part of the costs might actually be reduced. Farmers should thus focus on the part of the costs of production disorders that can be avoided, rather than on the total economic impact of the disorder.

The general focus in scientific studies on estimating only failure costs for production disorders reveals two major challenges when such outcomes are used to support the decision making at the farm level. The first challenge is that most studies focus on single disorders and use generic assumptions. The assumptions used vary between studies which limits comparability of failure costs for the same production disorder. Furthermore, farmers may perceive that the use of generic estimates does not reflect their own farming conditions and do not acknowledge study outcomes to be true for their farm. The second challenge is that hardly any study estimates the costs of multiple production disorders in one comparable study. The lack of comparability between study outcomes does not support decision making, as it makes prioritization of management efforts (i.e. allocation of limited resources) among production disorders impossible. To aid the decision making of a dairy farmer, the economic impact of different disorders should be estimated in a structured and comparable manner, using the most specific farm input possible, both from the technical (e.g., milk production, incidence levels, treatments) and economic point of view. Currently such an assessment approach is lacking.

Next to incomparability and lack of farm data specificity, there are hardly any economic evaluations of individual preventive measures for improving the animal health status and reducing the impact of a production disorder. To illustrate, a recent review by Hogeveen et al. (2019) on mastitis revealed a total of 19 studies estimating failure costs of mastitis, of which only 3 studies1, in some form, included both failure and preventive costs. Mastitis is believed to be the production disorder which is most extensively studied and for the other production disorders, there are no studies reporting both failure and preventive costs. Under certain conditions, small interventions or intervention practices can be limited to very specific conditions, e.g. the success of a certain therapy or intervention measure to treat animals (Roberson et al., 2004; McDougall et al., 2016; Mammi et al., 2021). Although these intervention strategies have been well studied technically, they have rarely been evaluated from an economic point of view. Taking into account the economic 'trade-off' optimization presented in the previous section. It is quite possible that the failure costs are alleviated, whilst the preventive costs penalize the farmer for improving animal health. It is important that such specific measures are evaluated economically to ensure that the farmer makes the right decision, given the specific conditions of his farm. Currently, such work is lacking to support good animal health decision making.

In the field of animal health economics, it is often assumed that farmers are acting economically rational, i.e., being profit maximisers. Bergevoet at al. (2004), Hansen and Greve (2014) and Graskemper et al. (2022) described that farmers set different goals. For example, farmers were found to put higher values on enjoying life, maintaining a certain lifestyle or acting independently while generating a sufficient income, above maximizing income. Although this should not be seen as an excuse to not include economics in the decision process of animal health management. It broadens the discussion when farmers decide to implement certain preventive animal health measures, so that it is not just about technical or economic features, but also includes a social aspect. In a study performed by Valeeva et al. (2007) it was explored which factors motivate farmers to improve mastitis management. In this study 'job satisfaction' and 'overall situation on the farm' were deemed more important than failure costs of mastitis. Although economics is important in supporting the animal health decision making process, it is equally important to consider how important animal health management actually is to the farmer in relation to the other management areas that compete for the farm's resources. Until now, no such work has been conducted for dairy farmers. The importance of farmer's preferences in relation to the adoption of health management advice should not be underestimated as this may influence the degree of implementation.

Based on the description above it is clear that production disorders have the potential to incur significant losses on farm level. However, to-date, no specific attention has been paid on how production disorders can be better management at the individual farm level from an economic perspective. For a better decision support on farm level the following shortcomings need to be addressed:

1) Due to the use of generic data farmers may feel that reported failure costs do not reflect their own farming conditions.

2) Cost studies focusing only on failure costs estimations (disease impact) neglect the potential reduction of disease incidence and failure costs by improved health management and the associated increased preventive costs.

3) Preventive animal health management measures are rarely evaluated from an economic perspective.

4) In general, there is a poor understanding on the importance of animal health management of the individual dairy farmer.

4. OBJECTIVES OF THIS DISSERTATION

The overall objective of this dissertation was to gain farm specific insights in 'how-to' manage dairy cattle production disorders from an economic perspective to support the farmer's decision-making process.

This objective was reached by answering the following research questions:

- Can we tailor the failure costs for multiple production disorders such that they reflect the individual farm conditions and that they can be directly compared with each other?
- What is the relation between failure and preventive costs associated with a production disorder on individual dairy farms?
- Can the economic impact of a preventive management intervention on a production disorder be evaluated, such that it takes into accounts the individual conditions of farms?
- Which priority do farmers give to animal health management in relation to other management areas?

5. OUTLINE OF THIS DISSERTATION

This dissertation consists of a general introduction (Chapter 1), followed by four research papers (Chapter 2-5) each addressing one research question, and ends with a general discussion in which a synthesis of the results is presented (Chapter 6).

Chapter 2 Presents the failure costs of the four production disorders affecting dairy cattle: mastitis, ketosis, lameness and metritis. It explores the failure costs for four different countries (Sweden, Spain, Germany and France) using empiric data for both technical and price input.

Chapter 3 Identifies the total costs of mastitis as a sum of both failure costs and preventive costs with the use of empiric input data on technical input. It includes a broad range of preventive measures applied at the farm level and their respective preventive costs, and includes routinely collected farm data combined (e.g., milk production and individual somatic cell count) with veterinary assessment of clinical mastitis.

Chapter 4 Assesses how a single health management intervention on pain treatment during a case of mastitis post-conception impacts farm income.

It includes a bio-dynamic model to simulate individual dairy cow places and includes all relevant parameters that affect a cow with clinical mastitis, including fertility.

Chapter 5 Explores the preference of individual dairy farmers from France, Germany, Spain and Sweden towards animal health in relation to other fields of management. Adaptive conjoint analysis is used to elicit these trade-off decisions.

Based on the studies performed, a novel economic framework is proposed to better inform farmers on where to allocate resources for various production disorders on an individual farm level to better manage dairy production disorders. This framework is addressed in the concluding discussion (Chapter 6) along with the main conclusion and recommendations of this dissertation.

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2

Chapter 2

Farm-specific failure costs of production diseases in dairy cows on European organic dairy farms

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1. ABSTRACT

On-farm decision support in animal health management requires a tailor-made failure costs (FC) assessment of production diseases for the individual farm. In our study we defined a generic framework to estimate the FC of production diseases in dairy cows. We converted the framework to a practical tool in which the farm-specific FC of mastitis, ketosis, lameness and metritis were estimated for 162 organic dairy farms in four European countries. Along with the structure of the framework, the tool required three distinct types of model input: performance input (relating to herd performance parameters), consequential input (related to the consequences of the diseases) and economic input (related to price levels). Input was derived from official herd recordings (e.g. test-day records and animal health recordings) and farmers' responses (e.g. questionnaire replies). The average FC of mastitis, ketosis, lameness and metritis amounted to €96, €21, €43 and €10 per cow per year, respectively. The variation in FC outcomes was highly variable between farmers and countries. Overall ranking of the diseases based on absolute values was the same for all countries, with mastitis being the costliest disease followed in order by lameness, ketosis, and metritis. Farm specific estimates can be used to rank production related diseases in terms of their associated failure costs and thus provide valuable insights for herd health management. The practical calculation tool developed in this study should be considered by farmers or herd health advisors to support their animal health practices or advice.

2. INTRODUCTION

For dairy farmers keeping animals healthy is one of many management areas that requires attention. Although animal health management is deemed important by dairy farmers (Valeeva et al., 2007; Van Soest et al., 2015; Jones et al., 2016) conflicts arise when other management areas compete for the available resources on time, labour and finance. Within the animal health management domain, similar conflicts also arise when farmers must decide where to allocate the restricted resources to maintain a healthy herd in a most effective way (Singer et al., 2011). This is a complex decision considering that animals become affected by different diseases each with its own characteristics and impact. The most prevalent diseases on EU dairy farms are endemic and the demand for high productivity from each animal may, for some diseases, increase prevalence levels further (Gröhn et al., 1995; Fleischer et al., 2001; Vanholder et al., 2015). Common production diseases include: mastitis, ketosis, lameness and metritis which have been reported at an average prevalence of 28%, 47%, 69% and 69%, respectively (Urton et al., 2005; van der Linde et al., 2010; Lam et al., 2013; Vanholder et al., 2015). Each of these diseases is costly and affects the overall herd performance through a decreasing production level or increasing number of treatments, labour requirements and involuntary culling. The costs associated with this reduced performance are referred to as failure costs (FC) (Hogeveen et al., 2011). The FC of mastitis , ketosis, lameness and metritis have been reported at the range of € 112 - € 946 (Hagnestam-Nielsen and Ostergaard, 2009; Sørensen et al., 2010; Heikkilä et al., 2012a), € 72 - € 442 (McArt et al., 2015; Raboisson et al., 2015), € 121 - € 216 (Bruijnis et al., 2010; Cha et al., 2010) and € 92 per case (Bartlett et al., 1986), respectively. Variations in costs estimates were depending on factors such as form (clinical or subclinical), pathogen and severity. Each of these diseases, given their occurrence and economic impact, have the potential to incur significant losses to farm income.

The variation in farm performance as indicated by milk production levels, and in price levels, such as: milk price and feed price, varies greatly between countries and even between farmers within the same country. Consequently, general FC estimates are unlikely to represent the individual farm FC and are therefore unsuitable for on farm decision support. With the exception of the studies of Huijps et al. (2008) and van Soest et al. (2016), where FC estimates of mastitis were made farm specific by using empirical data, all other economic studies on the FC of production diseases were based on model simulation techniques (e.g., Swinkels et al., 2005; Halasa et al., 2009a; McArt et al., 2015). Most simulation models represent a generic farm and assume an average: herd size, incidence level, production level and price levels. Which makes a direct comparison of FC between multiple diseases almost impossible on the individual farm level. In order to be able to set priorities within the animal health management domain farmers require FC estimates for the various diseases in which their specific farm situation is represented and comparisons between diseases can be made. Facilitating such estimations requires a generic framework which takes into account all farm specific technical and costs components for each disease. At the same time transparency to the farmer (i.e., the decision maker) on both model in- and output should be warranted. When FC lack the use of farm specific information on disease prevalence levels, herd performance data and price levels, not only the estimate might be wrong, but moreover the farmers may feel that the provided economic estimates do not represent their specific farm situation which may lead to distrust of the presented FC. In such situations farmers may decide to not take further action to improve their animal health situation.

Besides the relevancy of reducing the disease incidence from an economic perspective, reduction is also desirable from a societal perspective. Within organic farming one of the main principles is to aim for high levels of animal health and welfare (International Federation of Organic Agriculture Movements, 2005). As such, consumers expect a higher animal health status on organic farms than on conventional ones (Hughner et al., 2007) The animal health status on organic dairy farms is, on average, not better than that in the conventional sector (Sundrum, 2001; Hovi et al., 2003; Sutherland et al., 2013; van Wagenberg et al., 2017). Assuring a high animal health status in organic farming is therefore crucial to comply with consumer expectations to earn the bonus price they are receiving. Both economic and non-economic argumentation may stimulate organic farmers to take action to improve animal health status (Jansen et al., 2009) in which the economic argument may be more important than the non-economic argument to rationalise decision making. Occurrence of one or more production diseases directly affects farm income through increased treatment. Whereas other, more indirect effects, are less visible considering that the associated effects are less immediate or notable to the dairy farmer, such as: increased culling or gradual milk production losses over time. For a dairy farmer it is hard to assess the economic impact for each of the different production diseases considering that multiple production diseases may be present on the farm at the same time. Economic assessment of the current disease status is a vital component in animal health management as the FC estimates serve as an evaluation for farmers on where and how the allocation of resources has affected farm finance and as outlook on which production disease may be prioritised over another.

Consequently, the aim of our study was to estimate the farm specific FC of mastitis, ketosis, lameness and (endo)metritis on European organic dairy farms, by means of an farm specific tool, and to explore the variation in FC between and within EU countries for the different diseases.

3. MATERIAL AND METHODS

A general framework was developed to estimate the FC of production diseases in a structural approach. Following this approach, a functional tool was developed to estimate the FC of mastitis, ketosis, lameness and metritis on individual farms. In the developed tool specific attention was given to allow for individual farm characteristics on performance, disease and price levels. Finally, the tool was parametrised for and applied on organic dairy farms in four European countries: France, Germany, Spain and Sweden.

FRAMEWORK AND TOOL TO ESTIMATE FARM SPECIFIC FC OF PRODUCTION DISEASES

The framework to estimate the FC of production diseases is presented in Figure 1. To estimate the FC we were interested in the marginal effect of each production disease on farm income. Therefore, the use of the partial budgeting technique was most appropriate. Using the partial budgeting technique, only those cost elements that were actually affected by each production disease were included (Dijkhuizen and Morris, 1997). In our study FC consisted of three main cost elements: milk production losses, treatment and culling. Milk production losses included the losses associated with, both, the clinical and subclinical forms of a disease. Treatment accounted for the labour required for treatment, medication (either conventional or alternative therapy), veterinary visits and discarded milk (due to medication which requires an obligatory withdrawal period). Culling included the premature removal (slaughter) or death of an animal as a result of a disease.

Following the generic framework, a practical tool was developed in Microsoft Excel (Microsoft Corp., Redmond, WA) such that the FC of mastitis, ketosis, lameness and metritis can be estimated for an individual farm. The developed tool is available upon request from the corresponding author. The FC estimations are assumed multiple exclusive, e.g. no interaction between the diseases is assumed, and FC are estimated separately for each disease to prevent double counting production losses. Hence, FC for the different diseases can be compared with each other but cannot be summed together.

Application of the tool to assess the indicated FC costs elements requires three types of input: performance related input, input related to the consequences of the disease and economic input on price levels. Performance input relates to the performance of the herd and includes: the number of clinical and subclinical cases of a disease, the number of death or removed cows due to the disease, average milk production per cow per year (kg milk per cow per year) and average milk production per cow per

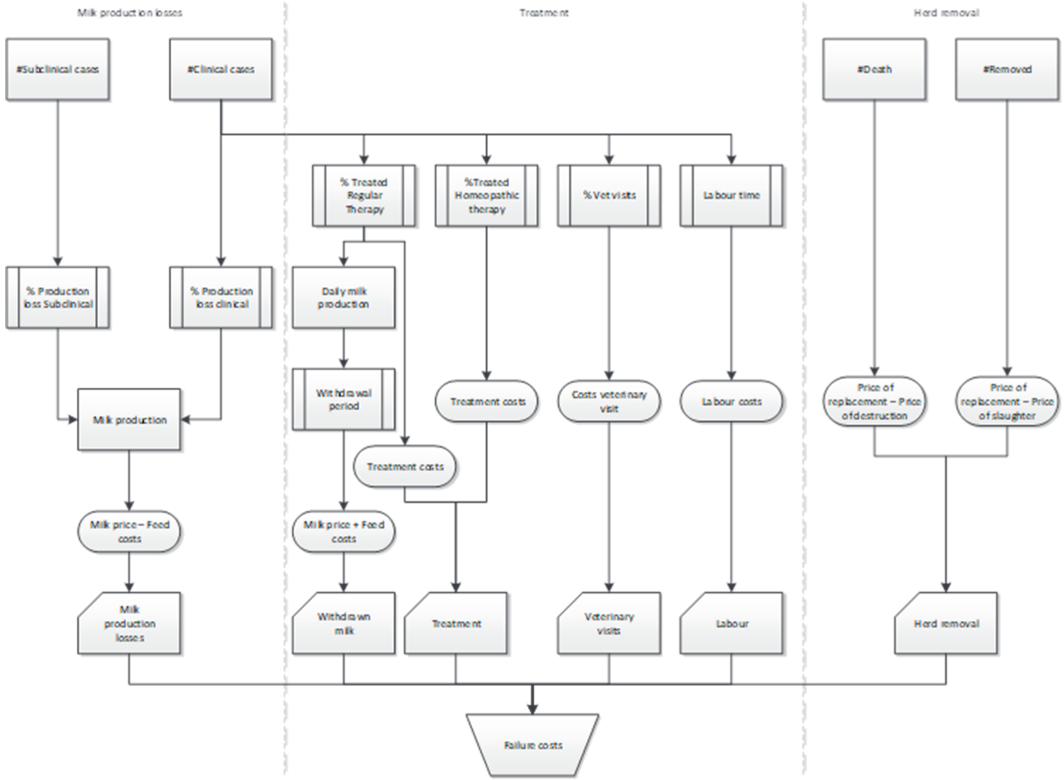

Figure 1 Overview of the generic framework to estimate the FC of production-related disorders on the farm level consisting of the three main cost categories: milk production loss, treatment and culling. Model input requires performance input (squares), consequential input (squares within squares) and economic input (rounds).

day (kg milk per cow per day). Input related to the consequences of a disease includes milk production losses associated with a clinical or subclinical case (expressed as a percentage of average milk production per cow per year), withdrawal period (days), percentage of clinical cases treated with conventional or alternative therapy (%), labour requirements to treat a clinical case (hour per treated case) and percentage of clinical cases which require a veterinary visit (% per clinical case). Economic input relates to the on-farm price levels and includes: the price of milk (€ per kg milk), feed costs (€ per kg milk), price of conventional treatment (€ per conventional treatment), price of alternative treatment (€ per alternative treatment), price of a veterinary visit (€ per veterinary visit), labour costs (€ per hour), replacement costs (€ per removed or death animal due to disease), costs of destruction (€ per death animal due to disease) and returns on selling an animal to the slaughter house (€ per slaughtered animal).

STUDY POPULATION.

To estimate the farm specific FC, the tool has been applied to a total of 162 EU organic dairy farms in France (n=39), Germany (n=60), Spain (n=23) and Sweden (n=40). This study on FC was part of a larger EU funded research project, aimed to improve animal health status on organic dairy farms in the EU (IMPRO – Impact matrix analysis and cost-benefit calculations to improve management practices regarding health status in organic dairy farming). The organic dairy farms from the four countries participating in this project represented the variation found in size, share and degree of settlement of organic development of organic dairy farms within Europe (Van Soest et al., 2015). More information on the selection process of the farmers and participating regions can be found in Van Soest et al. (Van Soest et al., 2015) and Krieger et al. (2017).

PARAMETRISATION: STAGE 1

Input data was derived from various data sources: herd recordings, literature and directly obtained from the farmer, the latter two were readily available. Therefore, Parameterization of the tool occurred in two stages: 1) prior to the on farm application by the use of official herd recordings data and literature data and 2) during the actual on farm application by means of information directly obtained from the farmer. Official herd recordings included: treatments and disease incidence levels, and test-day milk recordings, and was initially collected for the purpose of other research aims within the IMPRO project (Krieger et al., 2016). Data derived from the official herd recordings was only used for the performance related input. Herd recordings that could be entered directly in the tool were (stage 1 of parametrization): the number of cases of clinical mastitis and the number of dairy cows in the different lameness classes (non, moderate or severe). Lameness scores for each herd were available from the preceding farm visits and performed following the Welfare Quality® Protocol (2009) and clinical mastitis prevalence was derived from health ledgers (Krieger et al., 2016). The remaining herd recorded data needed to be processed first. The milk production data was aggregated at the farm level such that the average milk yield per cow per year was entered in the tool. Based on each test-day-date record the average number of lactating dairy cows on the farm during the last year was estimated. For each test-day record date the distribution among lactating dairy cows in any of the following somatic cell count (SCC) categories was determined: <50, 50-100, 100-200, 200-300, 300-400 and >400 x1,000 cells per ml. The average distribution among SCC classes on a farm during the last year was thereafter determined and used as an indicator for the milk production losses associated with subclinical mastitis (Huijps et al., 2008; Halasa et al., 2009b). Based on the test-day-records the number of dairy cows with a fat-protein-ratio (FPR) >1.5 during their first 100 days in lactation during the last year was determined. The FPR was used as an indicator for the total number of animals with subclinical ketosis on the farm (Duffield et al., 1997). All performance related input is presented in Table 1.

Data derived from literature was collected from scientific literature or country specific professional journals and included: the assumptions on milk production losses due to disease and withdrawal period associated with treatment (Table 2), and the most recent country specific organic price levels (Table 3). Each of these parameters were administered to the tool as part of stage 1 of the parametrization.

Due to the specific nature of each disease specific changes to the framework were required for some cost components. Milk production losses associated with ketosis were solely estimated for cows with subclinical ketosis. Milk production losses associated with clinical ketosis were excluded to prevent overestimation of milk production losses associated with ketosis. Production loss estimates of mastitis, included both clinical and subclinical production losses which is due to the specific nature of both diseases and moment of occurrence (Barkema et al., 1998; Suthar et al., 2013). Milk production losses associated with metritis were assumed to be parity specific (Rajala-Schultz et al., 1999). The average replacement rate on each farm was used to determine the average distribution of dairy cows over parity

1, 2, 3 and ≥4 and the corresponding production losses. No milk production losses were assumed to be associated with endometritis. For both metritis and endometritis no subclinical forms were assumed. Considering the specific circumstances regarding alternative treatment practices in organic farming it was assumed that 80% of all treated cows received regular veterinary recommended treatment (conventional therapy) and 25% of all treated cows received alternative treatment, if not specified otherwise by the farmer. During the farm visits, cases of clinical mastitis and clinical lameness could, when extra information on treatment was available, be further specified by the farmer using the following categories: 1) treated cases with antimicrobials 2) treated cases without antimicrobials 3) treated cases with alternative treatment or 4) untreated cases. The milk withdrawal periods were based on manufacturers' norm for the relevant antimicrobials and organic legislation. Labour requirements to treat one case of a disease was the amount of labour required to fully service one case of the disease. Data derived from literature was either used for the consequential data input or to set reference price levels.

Table 1 Technical input parameters, derived from test-day records, herd health recordings/ledgers or via a questionnaire response of the farmer, mean values reported per country (respective minimum; maximum reported values in parentheses).

Parameter	DE (n=60)	ES (n=23)	FR (n=39)	SE (n=40)
Dairy cows (n/yr)	76 (19; 314)	59 (13; 392)	63 (7; 135)	91 (29; 395)
Milk production (kg/cow/yr)	6,577 (3,420; 9,828)	6,301 (3,000; 8,500)	5,522 (3,193; 8,108)	8,939 (5,912; 10,634)
Clinical mastitis (%)	21 (3; 75)	40 (19; 85)	33 (2; 108[1])	10 (0; 27)
Clinical ketosis (%)	1 (0; 11)	1 (0; 10)	0 (0; 4)	2 (0; 12)
FPR >1.5 first 100 DIM (%)	30 (6; 72)	4 (0; 18)	11 (0; 34)	20 (6; 35)
Metritis (%)	8 (0; 40)	4 (0; 15)	2 (0; 14)	2 (0; 12)
Endometritis (%)	4 (0; 20)	3 (0; 14)	4 (0; 46)	3 (0; 14)
Lameness scoring				
Not lame (%)	75 (10; 100)	88 (73; 100)	71 (0; 100)	94 (75; 100)
Moderate (%)	15 (0; 44)	10 (0; 27)	22 (0; 57)	5 (0; 24)
Severe (%)	10 (0; 77)	0 (0; 3)	7 (0; 84)	1 (0; 9)
SCC classes (%)[1]				
<50	22 (5; 52)	23 (7; 41)	22 (0; 50)	37 (21; 63)
50-100	25 (15; 42)	17 (7; 31)	21 (0; 33)	21 (13; 27)
100-200	24 (13; 33)	20 (8; 33)	18 (3; 27)	18 (12; 24)
200-300	10 (3; 15)	10 (5; 19)	10 (7; 14)	7 (2; 11)
300-400	5 (1; 11)	6 (3; 11)	11 (2; 23)	4 (1; 9)
>400	13 (3; 29)	23 (9; 47)	20 (0; 66)	13 (4; 26)
Bulk tank somatic cell count (x1,000 cells/ml)	NA[3]	NA[3]	308 (155; 507)	NA[3]
Annual replacement rate (%)	19 (1; 48)	17 (4; 36)	24 (3; 39)	31 (10; 59)
Culled cows				
Mastitis (n/yr)	6 (0; 25)	3 (0; 21)	5 (0; 29)	10 (0; 25)
Ketosis (n/yr)	0 (0; 12)	0 (0; 0)	0 (0; 0)	0 (0; 1)
Lameness (n/yr)	3 (0; 13)	1 (0; 7)	2 (0; 9)	2 (0; 12)
Metritis (n/yr)	2 (0; 16)	0 (0; 0)	0 (0; 4)	0 (0; 3)
Destructed/Death cows				
Mastitis (n/yr)	0 (0; 3)	0 (0; 5)	0 (0; 2)	1 (0; 14)
Ketosis (n/yr)	0 (0; 0)	0 (0; 0)	0 (0; 2)	0 (0; 3)

Lameness (n/yr)	0 (0; 5)	0 (0; 3)	0 (0; 6)	1 (0; 4)
Metritis (n/yr)	0 (0; 2)	0 (0; 0)	0 (0; 0)	0 (0; 1)

1 Value larger than 100 suggesting recurring cases of clinical mastitis

2 Differences not equal to 100 due to rounding

3 NA = Not applicable

Table 2 Default technical input parameters related to the consequences of a disease, derived from literature, experts' knowledge, authors' expertise or manufacturers' norm, milk production losses (presented for each of the various disease classes), milk withdrawal period for use of antimicrobials.

Description	Value	Reference
Milk production losses (% of 305d milk production)		
Clinical mastitis	5	Seegers et al. (2003), McDougall et al. (2009)
SCC classes		Huijps et al. (Huijps et al., 2008)
<50	0	
50-100	0.5	
100-200	1.75	
200-300	2.65	
300-400	3.25	
>400	8	
Ketosis		
FPR[1] >1.5 first 100 DIM	5	Bareille et al. (Bareille et al., 2003)
Lameness classes		Green et al. (Green et al., 2002), Bicalho et al. (2008) and Bruijnis et al. (Bruijnis et al., 2010)
Non	0	
Moderate	3	
Severe	8	
Metritis parity classes		Rajala and Gröhn (1998)
P1	0.28	
P2	0.26	
P3	0.84	
P4+	0.54	
Endometritis	0	
Milk withdrawal period antimicrobials (days)		
Mastitis	6	Manufacturers' norm
Ketosis	NA[2]	
Lameness	7	Manufacturers' norm
Metritis	5	Manufacturers' norm
Endometritis	NA[2]	
Labour requirements (min / treatment / clinical case)		
Mastitis	45	Huijps et al. (Huijps et al., 2008), van Soest et al. (van Soest et al., 2016)
Ketosis	20	Experts' knowledge and authors' expertise
Lameness	70	Bruijnis et al. (Bruijnis et al., 2010)
Metritis	30	Experts' knowledge and authors' expertise
Endometritis	15	Experts' knowledge and authors' expertise

[1] FPR = Fat / Protein ratio

[2] NA = Not applicable

Table 3 Economic input parameters and range for DE (n=60), ES (n=21), FR (n=39) and SE (n=40), percentage of dairy farmers that made an actual change and reference values.

Variable	Country	Reference value	Farmers adjusting reference	Mean adjusted values (min; max)
Milk price (€/kg milk)				
	DE	0.41	95%	0.45 (0.37; 0.55)
	ES	0.40	78%	0.47 (0.40; 1.00)
	FR	0.41	74%	0.44 (0.37; 1.00)
	SE	0.36	93%	0.45 (0.40; 0.52)
Feed price (€/kg milk)				
	DE	0.15	92%	0.20 (0.07; 0.34)
	ES	0.14	61%	0.17 (0.12; 0.40)
	FR	0.11	56%	0.10 (0.03; 0.15)
	SE	0.13	58%	0.17 (0.12; 0.29)
Labour (€/hr)				
	DE	20	52%	17 (5; 25)
	ES	20	52%	15 (3; 20)
	FR	20	41%	19 (5; 50)
	SE	21	53%	22 (11; 50)
Replacement value dairy cow (€/cow)				
	DE	1,300	78%	1,402 (900; 1,800)
	ES	1,500	43%	1,535 (1,000; 2,200)
	FR	1,400	41%	1,351 (900; 1,800)
	SE	1,070	100%	1,217 (792; 1,650)
Destruction costs dairy cow (€/cow)				
	DE	170	53%	114 (5; 200)
	ES	170	61%	110 (2; 230)
	FR	170	28%	149 (37; 200)
	SE	152	100%	164 (131; 902)
Slaughter price dairy cow (€/cow)				
	DE	555	98%	842 (110; 1,433)
	ES	555	74%	492 (250; 700)
	FR	555	72%	838 (150; 1,238)
	SE	495	100%	807 (344; 1,127)
Penalties paid (€/yr)				
	DE	-	5%	637 (50; 1,000)
	ES	-	-	-
	FR	-	46%	1,434 (302; 4,642)
	SE	-	55%	527 (26; 2,258)
Bonuses missed (€/yr)				
	DE	-	10%	555 (50; 1,617)
	ES	-	-	- (-; -)
	FR	-	10%	1,121 (616; 1,616)
	SE	-	75%	2,168 (-; 6,732)

PARAMETRIZATION: STAGE 2

Data missing or not available from either official herd recordings or literature was asked directly from the dairy farmer during the application of the tool and was part of stage 2 of tool parametrization. For this purpose, a postal questionnaire was sent out preceding the farm visits. Farmers were asked to complete the questionnaire before the farm visit to facilitate the data entry during the visit. This preparing questionnaire included questions regarding price levels, culling, disease incidence levels and applied treatments. More specific, farmers were requested to indicate how many of their cows were treated for ketosis (prevalence of clinical ketosis), metritis (prevalence of metritis) and endometritis (prevalence of endometritis). Furthermore, farmers were asked to indicate the number of cows culled for mastitis, lameness, ketosis and (endo)metritis, separately, and to do the same for the number of cows dead on the farm. Thereafter the average herd replacement rate was asked. Requested economic input was the average received milk price (€ per kg milk), feed costs (including costs of roughage and concentrates, € per kg milk), labour costs (€ per hour), replacement costs (€ per replaced dairy cow), costs of destruction and collection from the farm (€ per destructed dairy cow), penalties paid last year for having a too high cell count (€ per year) and bonuses missed for having a too high cell count (€ per year). The questions relating to the economic input parameters were accompanied by country-specific reference values. The reference values were derived from professional literature and expert knowledge as indicated in Table 3.

ON FARM TOOL APPLICATION.

The farm visits were performed by native speaking researchers. The researchers received a training on how to work with the tool and to address potential questions that may arise during the visits. Moreover, since multiple research aims were performed during each visit a visiting protocol was set up to ensure that each farm visit proceeded in a similar manner.

Based on the collected herd record data (Table 1) and literature data (Tables 2) and assumed price levels (Table 3) the tool was partly parametrised prior to the farm visit, stage 1 of parametrization. During the farm visits these prepared inputs were presented and discussed with the farmer. After presenting the collected herd record data, the replies on the preparing questionnaire were collected and administered in the tool, stage 2 of parametrization. When farmers were uncertain about a value of a certain input parameter they received a more detailed explanation of the parameter's meaning. When, thereafter, farmers were not able to derive a value the reference value (Table 2) was used. Finally, FC were calculated for each individual disease and presented to the participants. At any moment in time changes could be made to any of the inputs when any of the participants felt a value did not represent the farm specific circumstances.

STATISTICAL ANALYSIS

A statistical analysis was performed on the variables FC mastitis, ketosis, lameness and metritis (€ per cow per year) using SAS/ STAT® software (SAS Institute Inc., Cary, NC, USA). FC estimates are expressed in € per cow per year to correct for any effect of farm size on the outcome. Assumptions of normality of the FC was based on a graphical display of the farm-specific FC and a Shapiro-Wilk test. Depending on whether normality could be assumed, either parametric or non-parametric tests were performed. It was tested whether the FC for each disease varied between countries. Furthermore, the relative ranking of diseases within a country was tested to determine whether the relative order varied between countries. Finally, a correlation analysis was performed to explore how the FC of one disease may affect in- or decrease of other FC.

4. RESULTS

DESCRIPTIVE STATISTICS

Herd performance. Herd performance results are presented in Table 1. Herd size and milk production were found to be highly variable between farms with a minimum and maximum of, respectively, 7 – 395 dairy cows per farm and 3,000 – 10,634 kg milk per cow per year. The average herd size was 74 dairy cows per farm and average milk production was 6,867 kg milk per cow per year. The average prevalence was 24% for clinical mastitis and 1.2% for clinical ketosis. One farm reported no cases of clinical mastitis and 98 farms reported no cases of clinical ketosis. No distinction was made for recurring cases of any of the four diseases. One Spanish farm reported a prevalence of clinical mastitis of 108%, suggesting recurrent cases, although this was not scrutinized. For 28 out of the 39 French farms only bulk tank SCC, average 308 (x 1,000 cells/mL), was available. To determine the distribution of dairy cows in the various SCC classes, a distribution suggested by Huijps et al. (2008) was used to determine prevalence in the various SCC classes. The remaining 11 out of 39 French farms reported SCC distributions similar to the other countries. The average distribution of SCC for the German, Spanish and Swedish farms was 26%, 22%, 20, 9%, 6% and 16% for the respective SCC classes, <50, 50-100, 100-200, 200-300, 300-400 and >400 (x 1,000 cells/mL). The average prevalence of subclinical ketosis was 19%. On 6 farms no cases of subclinical ketosis were reported out of which 5 farms also reported no cases of clinical ketosis. On average, 80% of all animals were found non-lame, 14% moderately lame and 6% severely lame. On 2 farms all dairy cows were detected lame and on 12 farms no lame cows were reported. For metritis and endometritis, 58 farms indicated no occurrence of one of these diseases. Out of these, on 35 farms both metritis and endometritis did not occur.

Average replacement rate was 0.23 with a minimum of 0.01 and maximum of 0.59. The relatively low reported replacement rate on some farms may be an indication of the farmers' intention to increase herd size in the coming years. Total culling rate as a result of one of the four diseases was 10%, however, a total of 15 farms reported total culling rates larger than the replacement rate suggesting that some cows were removed for multiple reasons. This was not further scrutinized.

Consequences of a disease. With the exception of one change made by a German farmer, no changes were made to the input related to the consequences of a disease. The change made by the German farmer was to the withdrawal period of mastitis treatment, which was extended from 6 days to 12 days.

Economic descriptives. Most farmers indicated price levels other than the provided reference values. An overview of the percentage of farmers that actually changed the reference value and the resulting assessed average price levels is provided in Table 3. Reasons for changing the reference value were not asked to the farmers. Swedish farmers were most likely to change an economic input parameter. In comparison to the other EU farmers, they provided the highest percentage of changes with respect to six of the eight price input variables. French farmers were least likely to change an economic parameter. In comparison to the other EU farmers, they provided the lowest percentage of changes with respect to six of the eight price input variables. Milk price was most often given an alternative value, among the evaluated countries 74% to 95% of the farmers provided a farm specific milk price. Most changes to the reference value of feed costs were made by German farmers (92%) and least changes by French farmers (56%). Labour costs were, on average, reported highest in Sweden with € 22 per hour and reported lowest by Spanish farmers with € 15 per hour. None of the farmers reported no labour costs. The average reported heifer replacement value was € 1,363 per replaced cow. Spanish and Swedish farmers made the least changes to the reference replacement value, 43% and 41%, respectively. Spanish farmers indicated the highest average replacement value of € 1,535 per replaced cow. Spanish farmers reported, on average, the lowest destruction costs, € 110 per cow, and Swedish farmers the highest destruction costs, € 164. No Spanish farmer indicated that they had to pay additional penalties or missed any bonuses due to an elevated SCC. In contrast, 5%, 46% and 55% of the German, French and Swedish farmers indicated they had to pay penalties during the last year due to an elevated SCC of, on average, € 637, €1,434 and € 527, respectively. From the participating dairy farmers, 10%, 10% and 75% of the German, French and Swedish farmers missed a bonus due to an increased SCC of, on average, at a cost of € 555, € 1,121 and € 2,168, respectively.

FAILURE COSTS

Failure costs for all of the four diseases, and their respective cost components, are presented in Table 4. The total FC for mastitis were on average € 106, € 145, € 138 and € 124 per cow present per year for the German, Spanish, French and Swedish farmers, respectively. The lowest FC on an individual farm were equal to € 32 per cow per year and the highest reported FC were € 462 per cow per year, both on French farms. Overall, the largest contributors to the total FC of mastitis were milk production losses, both due to clinical and subclinical mastitis, and culling losses. On one French and one Swedish farm, negative removal costs were reported, suggesting an economic benefit following culling, which is theoretical possible when slaughter value exceeds the costs of replacement. The total FC for ketosis were on average € 28, € 4, € 11 and € 29 per cow present per year for the German, Spanish, French and Swedish farmers, respectively. The highest reported FC of ketosis were reported on a German farm, € 135 per cow per year, and the lowest FC were reported on both one Spanish and one French farm, € 0 per cow per year, following no reported cases of ketosis. The largest contributor to the total FC of ketosis was milk production losses. Nevertheless, on 4 farms the costs of culling exceeded the milk production losses. The total FC for lameness were on average € 48, € 31, € 53 and € 33 per cow per year for the German, Spanish, French and Swedish farmers, respectively. The highest reported FC of lameness were reported on a French farm, € 269 per cow per year, and lowest FC were negative and reported on a Swedish farm, - € 6 per cow per year. On the latter farm, losses were compensated by negative culling costs which were a consequence of revenues made from slaughter, which were higher than the total costs of replacement and destruction. The highest and

lowest FC, €269 and -€1 per cow per year, associated with lameness were found among French farmers. The total FC for metritis were on average € 21, € 5, € 4 and € 4 per cow per year for the German, Spanish, French and Swedish farmers, respectively. The highest FC were reported on a German farm, € 96 per cow per year, and the lowest reported costs were € 0 per cow per year and reported in each country. Milk production losses due to metritis, contrary to the other diseases, contributed only marginally to the total FC, whereas culling and discarding milk, following antimicrobial therapy, contributed the most.

A test for normality on the variables FC of mastitis, ketosis, lameness and metritis, expressed in € per cow per year, was performed and could not prove a normal distribution of the data. Therefore all relevant tests were performed using non-parametric tests. An overview of the variation in FC for each disease is presented in Figure 2 including any significant differences between countries, using a Kruskal-Wallis test. The FC of mastitis were found significantly higher on Spanish farms compared to German farms ($P<0.001$). The FC of ketosis were found lowest on Spanish farms ($P<0.01$) and both German and Swedish farms ($P<0.001$) had higher FC of ketosis compared to French farms. The FC of lameness were higher on German and French farms compared to the Spanish farms, respectively $P=0.03$ and $P=0.02$. The FC of

Table 4 Failure costs (FC) estimation for the four diseases (mastitis, ketosis, lameness and (endo)metritis) and the respective disease costs factors for each of the 4 different countries Germany (DE), Spain (ES), France (FR) and Sweden, expressed in € per cow per year (minimum; maximum in parentheses).

	DE (n=60)	**ES (n=23)**	**FR (n=39)**	**SE[1] (n=40)**
Mastitis				
Subclinical production losses	17 (2; 55)	37 (20; 74)	31 (2; 95)	13 (0; 37)
Clinical milk production losses	33 (12; 55)	51 (28; 90)	50 (15; 317)	43 (20; 84)
Discarded milk	11 (0; 32)	15 (0; 51)	17 (0; 65)	9 (0; 31)
Veterinary treatment	0.2 (0; 0.8)	0.4 (0.2; 0.9)	0.4 (0; 1.2)	0.4 (0; 0.9)
Medication	4 (0; 16)	5 (0; 15)	6 (0; 25)	4 (0; 12)
Homeopathic therapy	2 (0; 19)	4 (0; 30)	1 (0; 7)	0 (0; 0)
Labour	3 (0.3; 11)	4 (0.9; 11)	5 (0.3; 16)	2 (0; 5)
Culling	37 (0; 211)	29 (0; 205)	27 (-4[2]; 314)	52 (-19[2]; 259)
Total subclinical mastitis	33 (12; 55)	51 (28; 90)	50 (15; 317)	43 (20; 84)
Total clinical mastitis	73 (13; 316)	94 (43; 246)	87 (6; 335)	81 (9; 319)
Total FC mastitis	106 (36; 349)	145 (79; 294)	138 (32; 462)	124 (45; 361)
Ketosis				
Milk production losses	24 (7; 57)	3 (0; 16)	10 (0; 38)	25 (6; 47)
Discarded milk	0.0 (0; 0)	0 (0; 0)	0 (0; 0)	0 (0; 0)
Veterinary treatment	0.3 (0; 3)	0.3 (0; 2.4)	0.1 (0; 1)	0.8 (0; 5)
Medication	0.3 (0; 3)	0.3 (0; 2.4)	0.1 (0; 1)	0.3 (0; 2)
Homeopathic therapy	0.2 (0; 1)	0.1 (0; 1)	0 (0; 0.5)	0.3 (0; 2)
Labour	0.3 (0; 2)	0.3 (0; 2)	0.1 (0; 0.9)	0.5 (0; 3)
Culling	3 (0; 93)	0 (0; 0)	0.6 (0; 22)	2 (0; 49)
Total FC ketosis	28 (7; 135)	4 (0; 16)	11 (0; 41)	29 (10; 77)
Lameness				
Milk production losses	21 (0; 139)	7 (0; 16)	22 (0; 143)	6 (0; 28)
Discarded milk	5 (0; 65)	7 (0; 21)	14 (0; 62)	6 (0; 25)
Veterinary treatment	0.4 (0; 3.1)	0 (0; 0.1)	0.3 (0; 3)	0 (0; 0.2)
Medication	0.6 (0; 2)	0.2 (0; 0.7)	0.6 (0; 2)	1 (0; 5)
Homeopathic therapy	0.8 (0; 12)	0.6 (0; 2)	2 (0; 6)	0 (0; 0)
Labour	0.6 (0; 5.1)	0 (0.1; 0.4)	0.4 (0; 6)	0.1 (0; 0.7)
Culling	20 (0; 169)	16 (0; 107)	14 (-1.5[2]; 92)	20 (-6[2]; 84)
Total FC lameness	48 (0; 257)	31 (0; 121)	53 (-1.4[2]; 269)	33 (-6[2]; 102)
(Endo)metritis				
Milk production losses	0.5 (0; 3)	0.3 (0; 1)	0.2 (0; 2)	0.2 (0; 1)
Discarded milk	6 (0; 23)	3 (0; 12)	1 (0; 11)	2 (0; 14)
Veterinary treatment	0.1 (0; 0.4)	0 (0; 0.2)	0 (0; 0.1)	0 (0; 0.1)
Medication	0.8 (0; 4)	0.4 (0; 2)	0.2 (0; 1)	0.2 (0; 1)
Homeopathic therapy	0.4 (0; 2)	0.2 (0; 0.8)	0.1 (0; 0.7)	0.1 (0; 0.6)
Labour	0.9 (0; 5)	0.4 (0; 2)	0.5 (0; 9)	0.4 (0; 2)
Culling	13 (-1[2]; 84)	0 (0; 0)	2 (0; 23)	0.9 (0; 17)
Total FC (endo)metritis	21 (0; 96)	5 (0; 16)	4 (0; 45)	4 (0; 21)

1 Costs estimations under Swedish circumstances were made in Swedish Krona (SEK) and converted to Euro in which 1SEK=€0.11

2 Negative values for culling occur when revenues from cow sales are higher than costs of rearing new heifer for replacement, thus representing a benefit

metritis was found highest on German farms compared to the other three countries $P \leq 0.001$.

Although the magnitude of FC for the four diseases varied between countries a Kruskal-Wallis test on the relative ranking on the individual farm of the four diseases by their FC estimates indicated that, for all countries, mastitis was the disease with the highest FC, followed by lameness, ketosis and metritis. Two exemptions existed; in Spain no significant difference was found between rank three and four which were ketosis and metritis and in Sweden no significant difference was found between rank two and three which were ketosis and lameness.

Spearman's rank correlation coefficient test revealed a positive and significant correlation coefficient between the FC of metritis and the FC of ketosis ($r_s = 0.21$, $P = 0.007$) and between the FC of metritis and the FC of lameness ($r_s = 0.28$, $P < 0.001$). Meaning that a subsequent increase of these variables may lead to an increase in the correlated variable, and/or vice-versa. However, based on the correlation test no causality can be assumed on which variables influences the other variable.

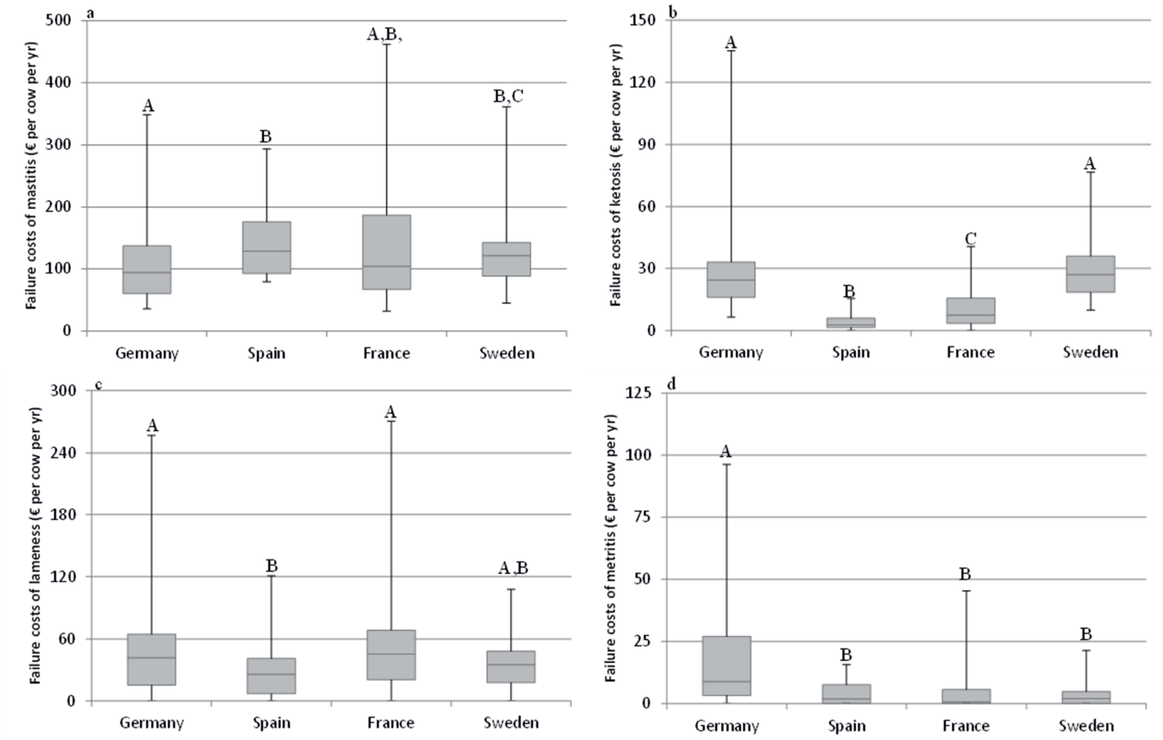

Figure 2a,b,c,d Boxplots for failure costs (€ per cow per year) of mastitis (a), ketosis (b), lameness (c) and metritis (d) for the four different countries. Significant differences between countries for each disorder are given, different letters indicate a significant difference at P < 0.05, following a non-parametric Kruskal-Wallis test.

5. DISCUSSION

Our study estimated the farm specific FC of four common production diseases, mastitis, ketosis, lameness and metritis on European organic dairy farms. FC estimations of production diseases on organic dairy farms have not been estimated previously. Moreover, the method used in this study estimates the FC of multiple diseases by setting up a framework which makes it possible to make on-farm comparisons on the economic impact of the diseases. A large variation in FC estimates both between and within the studied countries is reported. This variation is partly provoked by the differences in disease prevalence levels and partly by the variation in herd price levels. A comparison of the prevalence levels found in our study compared to a large set-up study on the prevalence levels of multiple postpartum diseases in conventional herds in 10 EU countries found similar variations in prevalence levels regarding mastitis, ketosis, lameness and metritis (Suthar et al., 2013). The average prevalence levels in that study tended to be lower than the prevalence levels reported in our study. Nevertheless, other studies reported prevalence levels in organic systems to be comparable to prevalence levels found in conventional systems (Hovi et al., 2003; Sutherland et al., 2013; van Wagenberg et al., 2017).

Herd health information in our study was partly derived from official recordings and partly reported by farmers. There is a potential bias in using farmers reports of the incidences of the different diseases which may over- or underestimate the true incidence levels (Bartlett et al., 2001; Richert et al., 2013a; b). In our study, the incidence of a large proportion of production diseases was established, based on test-day milk records such as: subclinical mastitis via SCC (Halasa et al., 2007) and subclinical ketosis via FPR during the first 100 days in milk (Duffield et al., 1997), or via an assessment made following a protocol, such as the Welfare Quality® assessment protocol for cattle. Usage of such data for on-farm FC estimates yields reduces farmers' perception bias. The information that is used in our study is the information available in practice and used in the decision-making process. Furthermore, the availability of information between countries differs and may be more evolved, such as the use of Bulk tank SCC vs. individual reports on SCC. To omit any reporting bias, the current farm information systems should adapt to include more routinely collected animal health related data, e.g., as part of new developed precision livestock farming technologies (Rutten et al., 2013), which may subsequently lead to more accurate FC estimates.

Recent simulation model studies on the FC of ketosis reported values of $289 or $203 per case of subclinical ketosis (McArt et al., 2015; Gohary et al., 2016). Conversion of these costs factors using the prevalence of subclinical ketosis from our study results in slightly higher FC estimations per unit of cow present. This could be a consequence of the fact that the other studies included additional cost factors which were not included in our study, such as: displaced abomasum, metritis and reduction in reproductive performance. Bruijnis et al. (2010) reported FC of lameness to average $75 per cow per year and Cha et al. (2010) reported FC of $120 to $216 per case depending on the type of lesion. The lower reported costs of lameness in our study may be a consequence of the relatively good hoof health status on the organic dairy farms included in our study. No recent estimates on the FC of metritis are mentioned in scientific literature. Similar levels of variation in FC of mastitis and a slightly higher average reported FC of mastitis were found in van Soest et al. (2016) in which also farm specific FC of mastitis were estimated for conventional Dutch dairy farms using a more systematic and precise data collection. The variation in FC estimates, found in our study, was larger than those found in the other studies. It could be stated that the average farm specific FC estimated in our study are at least comparable to those obtained by more complex estimation methods. At the same time our farm-specific FC estimates give a better representation of the actual variation between farms. The merit in our study thus lies in the fact that the

FC estimates in our study are farm specific whereas economic simulation models reflect only average farm situations.

Subclinical ketosis has been found to be associated with increased odds of developing metritis, clinical ketosis and displaced abomasum (Suthar et al., 2013). Correa et al. (1993) reveals a causal relation of ketosis on metritis. Metritis occurrence was however, also affected by other events such as stillbirth, dystocia and retained placenta factors not taken into account in this study. The latter effects have also been reported more recently by Potter et al. (2010). None of these mentioned interactions were reported by Heuer et al. (2001). These findings may provide a technical explanation on the found positive correlation between FC of ketosis and metritis in our study. Nevertheless, no technical explanation can be given on a correlation between metritis and lameness found in our study, whereas a technical explanation of a correlation between mastitis and ketosis (Raboisson et al., 2014) and lameness and ketosis (Heuer et al., 2001) can be given based on literature. This would suggest that a technical explanation on itself is insufficient to explain the correlation and other potential factors which may play an important role such as: stockmanship and housing conditions. The suggestion of reducing the FC of one disease and thereby benefiting in the reduction of the FC of other diseases (McArt et al., 2015), based on the findings in our study, may in practice not hold for all diseases. Future FC estimations should, therefore, be cautious in including such effects.

A first step towards a more farm specific FC estimate was made by Huijps et al. (2008) on the costs of mastitis. In that study a comparison was made between the perceived FC - as derived from the incidence and price levels as indicated by the farmer - and the reference FC as defined by the authors. A distinction was made between farmers overestimating and underestimating the FC, suggesting that the farmers' perceived values were inferior to the authors' base line values. In our study, this assumption was the other way around. Input provided by the farmer was assumed superior to the provided reference values. Reference values were only used when the farmer was unable to derive own input values. This assumption relates to the farm-centred approach: in which farmer and veterinarian are acknowledged as a trusted resource and are actively involved in the decision-making process which is hypothesized to have a positive effect on the adoption of new measures (Duval et al., 2016; Jones et al., 2016, 2017). Farm-centred FC estimations, such as carried out using the tool developed for this study, have merit during the on-farm decision making process as they are less complex to the user, adaptable to the individual farm and less time-consuming than simulation models. Although not further scrutinized, farmers may feel that the FC estimations reflect their farming situation, providing the farmer with better insights in the economic situation of animal health on their farm. The tailored FC estimation method used in our study can be an addition to the farm advice provided by e.g. the veterinarian and lead to an earlier intervention by the farmer to reduce the disease burden.

6. CONCLUSION

This study is the first to explore on-farm FC of four common production diseases on EU organic dairy farms. Using a structured method enabled a comparison of FC estimates on the individual farm for multiple production diseases. Generally, the FC of mastitis were found highest, followed by the FC of ketosis, lameness and metritis. The variation in FC outcomes was highly variable between farmers, indicating the need for farm specific estimations when advising farmers in their animal health management. It is believed that the farm-centred approach used in this study will aid the on-farm decision support in animal health.

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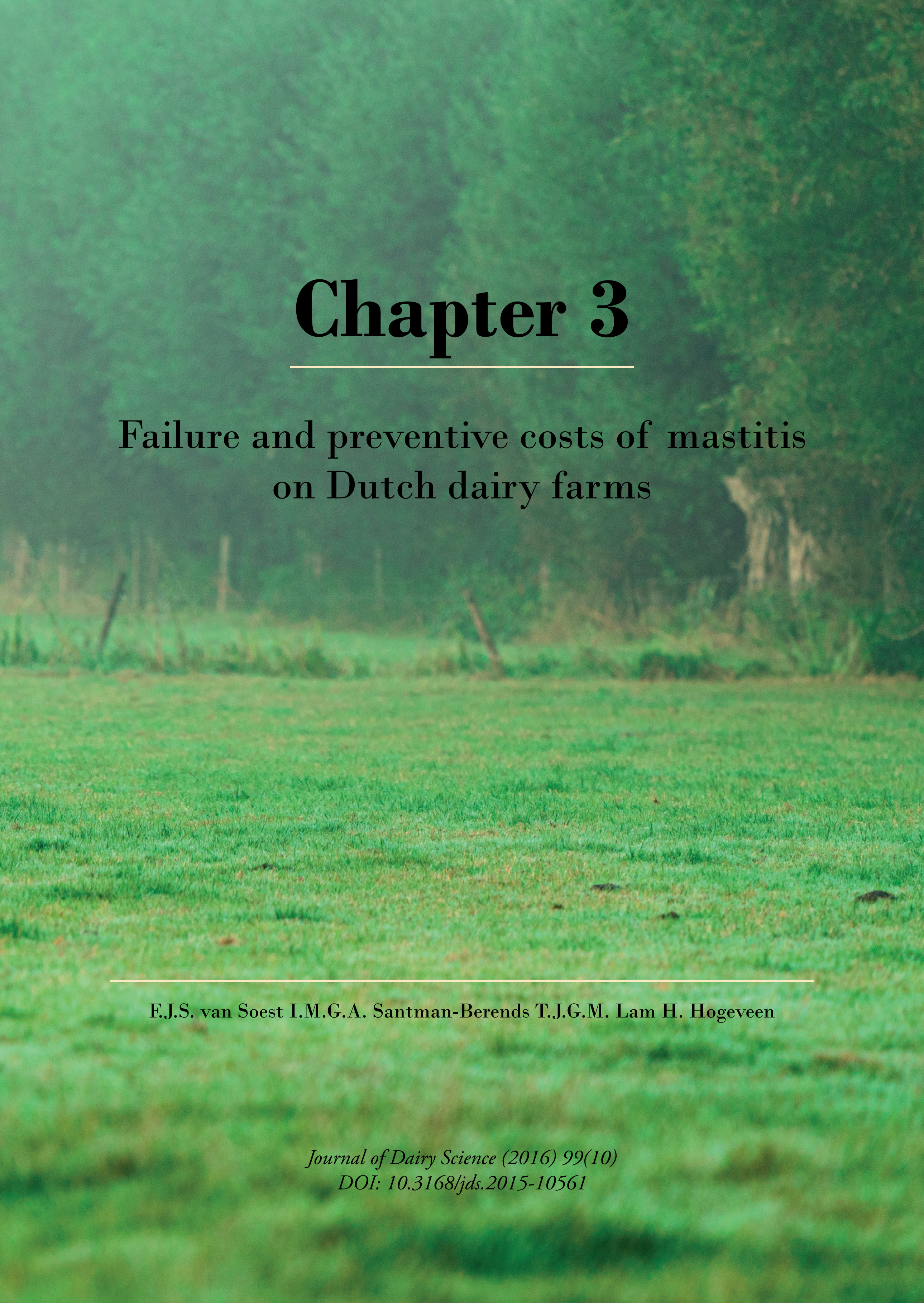

Chapter 3

Failure and preventive costs of mastitis on Dutch dairy farms

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1. ABSTRACT

Mastitis remains an important disease from an economic perspective. Nevertheless, most cost assessments of mastitis only include the direct costs associated with mastitis (e.g., production losses, culling and treatment), which we call failure costs (FC). Farmers, however, also invest time and money in controlling mastitis, the preventive costs (PC), which also need to be taken into account. To estimate the total costs of mastitis, we estimated both FC and PC. We combined multiple test-day milk records of 108 Dutch dairy farms, with information on the applied mastitis prevention measures and farmers' registration of clinical mastitis for individual dairy cows. The aim of this study was to estimate the total costs of mastitis and to give insight in the variation between farms. The total costs of mastitis were estimated at, on average, €240 / lactating cow per yr in which FC contributed €120 / lactating cow per yr and PC contributed to another €120 / lactating cow per yr. The costs of milk production losses, discarded milk and culling were the main contributors to the FC, respectively, €32, €20 and €20 / lactating cow per yr. Whereas, labor costs were the main contributor to the PC, next to consumables and investments, respectively €82, €34 and €4 / lactating cow per yr. The variation between farmers was found to be substantial, in which some farmers face both high FC and PC. This large variation between farmers may be due to structural differences between farms, different mastitis causing pathogens, the moment when preventive action is initiated, stockmanship or missing important measures in the PC estimates. The minimum FC were estimated at €34 / lactating cow per yr. All farmers initiated some preventive action to control or reduce mastitis. This indicates that farmers will always have mastitis related costs because mastitis will never be fully eradicated from a farm. Insights in both PC and FC of a specific farm will allow veterinary advisors and the respective farmer to assess whether the current udder health strategy is appropriate or whether, from an economic perspective, there is room for improvement.

2. INTRODUCTION

Mastitis, both clinical mastitis (CM) and subclinical mastitis (SCM), is a common endemic disease on dairy farms worldwide. Mastitis substantially affects animal health and welfare as well as farm income. The different aspects of mastitis and the associated economic impact have been the focus of a number of previous scientific studies. Huijps et al. (2009) estimated the costs of (sub)clinical mastitis in first parity cows at €31 / first parity cow per yr, with a corresponding incidence rate of CM of 0.15 / cow-year among first parity cows. Cha et al. (2011) estimated the costs of Gram positive, Gram negative and other mastitis causing pathogens, at $134, $211, and $95 / case with a corresponding incidence of 15.5, 12.6 and 16.2 CM cases / 100 cow-years. Similarly, Sørensen et al. (2010) found the costs of mastitis to vary from €149 to €570 / mastitis case, at an incidence varying from 3% to 5% per lactation, depending on the mastitis causing pathogen. Heikkilä et al. (2012), estimated the costs of mastitis at €458 /CM case or alternatively €147 / cow per yr with a corresponding incidence rate of CM varying from 0.31 to 0.38 / cow per yr, depending on the type of breed. Although estimates of the costs of mastitis differ, it is clear that mastitis has a substantial impact on farm economics. Mastitis does not only affect farm income, the costs of mastitis are directed throughout the dairy processing chain and also affect processors profitability (Geary et al., 2013).

All previous studies on the costs of mastitis only provide costs associated with production losses, culling and treatment. Farmers, however, also invest time and money in controlling mastitis (Huijps et al., 2010), aspects which are hardly ever taken into account in costs estimations. McInerney et al. (1992) suggested to make an economic distinction between expenditures and losses to estimate the total costs of a disease. Expenditures are defined as the costs made by the farmer to prevent or treat the disease. Whereas losses are defined as the costs of an animal being affected by the (sub)clinical disease (e.g. production losses, culling, discarded milk). Hogeveen et al.

(2011) suggested to divide the total costs of mastitis in failure costs (FC) and preventive costs (PC). The FC of mastitis consist of the costs associated with animals getting mastitis (e.g. due to production losses, veterinary treatment, antibiotics). The PC of mastitis consist of the costs associated with the management measures adopted by dairy farmers to prevent the animals of becoming affected by mastitis.

Insights in both FC and PC associated with mastitis are only sparsely available. Fourichon et al. (2001), estimated health-control costs on dairy farms, including mastitis. In that study, however, only health control measures were taken into account while FC were lacking. To the authors' knowledge, only 2 studies used a construct similar to the FC and PC, which they called losses and expenditures, to estimate the total costs of mastitis (McInerney et al., 1992; Yalcin et al., 1999). Yalcin et al. (1999), estimated both expenditures and losses associated with SCM in Scottish high bulk milk somatic cell count dairy herds and stated that 35% of the costs could be avoided. The expenditures related to CM were neglected in that study, which could be substantial. Although McInerney et al. (1992) included farm data to estimate both CM and SCM losses, in their study only 3 measures were evaluated.

Documenting the impact of mastitis as FC shows an important part of the economic impact of mastitis and the potential importance of its prevention. Insights in the FC as well as PC will give a more complete insight in the total costs associated with mastitis. In our study we used information on farm specific udder health management strategies, farmer registered CM incidence and multiple test-day milk records to determine the total costs of mastitis. Our aim was to estimate the total costs of mastitis as a construct of FC and PC and to provide insight in the variation between farms.

3. MATERIAL AND METHODS

DAIRY HERDS

Data from 108 Dutch dairy herds were available from previous work conducted by Santman-Berends et al. (2012). Herds were representative for Dutch dairy herds with more than 50 lactating cows of which the herd owner was younger than 50 yr. Farmers reported the number of cases of CM from January 2005 until December 2009. During this period, participating farmers were requested every month, by e-mail to report the number of CM cases in the previous month. If they did not reply, follow-up calls were made.

Test-day milk record data was collected from all dairy cows, of the participating herds, that were present in the period January 2007 to December 2009. Test-day milk record data were provided by the Dutch Royal Cattle Syndicate (CRV, Arnhem, the Netherlands) and contained information on individual cow records (milk production, somatic cell count (SCC), date of calving, date of culling and date of test-day record) for each of the participating herds. Test-day milk record data were used to determine the number of days each dairy cow was in lactation and to determine the associated milk production losses during the study period.

In the spring of 2008, the farmers were asked to participate and complete a questionnaire, which included amongst others, questions on mastitis management, milking process / technique and mastitis / dry cow treatment. A list of preventive management measures was derived from the questionnaire. Information on the applied measures was valid for 2008 and was used to estimate the PC for that year. The collected technical data, farmers report on CM cases, test-day milk record data and questionnaire data, was therefore set to be representative for the period January 1st, 2008, until December 31st, 2008. More information on the data used can be found in Santman-Berends et al. (2012).

TOTAL COSTS OF MASTITIS

The total costs of mastitis were determined as the sum of the FC and the PC.

Failure Costs. The FC of mastitis were divided into direct and indirect costs. The direct costs included the costs associated with treatment, such as veterinary visits and medication. The indirect costs were the costs associated with the consequences of (S)CM, such as milk production losses and culling.

The SCM milk production losses were estimated on cow level and based on the SCC of individual cows at each test-day record. For this we assume, based on the study of Halasa et al. (2009) that the individual cow does not meet the potential milk production when the SCC is elevated, SCC > 50,000 cells / mL. For dairy cow i the potential milk production (Y_{POTij}), expressed in kg milk per day, was determined as a function of the SCC_{ij} and realized daily milk production (Y_{ij}) at test-day record date j, based on a study by Halasa et al. (2009). The potential milk production was estimated for primiparous cows (age at the start of lactation < 1,030 days) as:

$$Y_{POTij} = Y_{ij} + (0.72 + \ln(SCC_{ij} - 0.22))$$

And for multiparous cows (age at the start of lactation ≥ 1,030 days) as:

$$Y_{POTij} = Y_{ij} + (1.9 + \ln(SCC_{ij} - 0.47))$$

Dairy cows, both primiparous and multiparous, with a SCC ≤ 50,000 cells / ml were assumed to have Y_{POTij} equal to Y_{ij}.

To estimate the milk production losses at farm level, test-day records were converted to test-day periods and finally merged to farm level. These test-day periods could, either be the period from 1) test-day record date to the next test day record date, 2) test-day record date to date of removal from the herd, 3) test day record-date to dry-off date or 4) date of calving to test-day record date. For each test-day period, information on the daily milk production, both potential and realized, at the begin and end of that period and the number of days in that period was determined. Since daily milk production was not known at removal dates or dry-off dates, for the test-day periods that included either a removal or drying off of the cow the daily milk production at the start of the test-day period then equaled the milk production at the end of that test-day period and vice versa. If no date of removal was registered, dairy cows were assumed to be removed from the herd (either by dead, sale or culling) at the last recorded test-day date. Date of drying off was not registered in the data and was therefore determined as the date of the following calving minus the average dry period of Dutch dairy cows in 2008 (64 days, CRV, 2010). When this resulted in a negative number of days in that period, the last known test-day record date within the corresponding parity was set as date of drying off. For test-day periods with either a start or end outside the study period, only the milk production from 1 January or until 31 December were considered. Assuming that daily milk production between the begin and end date of a test-day period changed linearly, the milk production on either 1st January 2008 or 31st December 2008 was determined via linear interpolation. For each test-day period the milk production in that period, both realized and potential, was determined as the area under the curve, assuming that daily milk production at the begin and end of each period was linear. Finally, the total, both realized and potential, milk production per farm in 2008 was estimated as the total amount of produced milk on the farm. The difference between the total realized and potential milk production per farm in 2008 was assumed to be the milk production loss due to SCM on the respective farm.

In the available data, CM cases were not linked to individual dairy cows. Therefore, each case of CM was assumed to have a relative total milk production loss of 5% of the average realized milk production of a dairy cow on a specific farm (Seegers et al., 2003). Since we calculated the milk production losses independently for CM as well as for increased SCC, there might be an overestimation of the milk production losses. In the sensitivity analysis (described elsewhere in this section), attention has been given to the effects of this possible overestimation.

The FC of CM included the costs of: milk production losses, discarded milk, culling and treatment (including veterinary visits, medication and labor). The cost calculations were based on Huijps et al. (2008). As of 2015, the EU milk quota system is abolished and contrary to the quota situation and using the marginal costs of milk, producing 1 kg milk extra now equals the milk price. This means that the economic loss of losing a kg of milk, equaled the milk price minus the price of concentrates. Discarding a kg of milk equaled the milk price plus the price of concentrates. Although the technical data is representative for farms in 2008 the cost estimates in this study were based on the price levels of 2015 to correspond to the current farming situation in the Netherlands. It was assumed that the milk that was produced by a cow that was treated with antibiotics, was discarded during the withdrawal period. The milk price was assumed to be €0.35 / kg milk and the feed price of concentrates was assumed to be €0.06 / kg milk (LEI, 2015). The average daily production per cow on a farm was used to estimate the amount of milk discarded due to treatment. The duration of the treatment and corresponding withdrawal period was assumed to be 6 days. A total of 80% of all animals diagnosed with CM was assumed to be treated with antibiotics. Labor costs were based on the amount of labor spent on treating each case of CM multiplied with the hourly wage of the farmer. The hourly wage was assumed to be the price of hired labor and was set at €20 / h (Vermeij, 2014). Veterinary visits were assumed to occur in 5% of all CM cases, and 15% of all cows suffering from CM were assumed to be culled due to mastitis. An overview of both technical and economic assumptions to estimate FC are presented in Table 1. Preventive Costs. The PC involved the costs associated with the implemented farm management measures to prevent animals from becoming affected by mastitis. The PC of each measure, generally, consisted of 3 cost factors, labor, consumables, and investments. Labor was the time necessary to perform the measure. Consumables consisted of the expenditures on used goods. Investments consisted of the depreciation costs of materials lasting longer than a year and associated interest. It was assumed that both, labor, and consumables were used half of the time, when a farmer indicated that the respective management measure was applied sometimes. Investments were not affected by the number of times a measure was applied.

Table 1 overview of market and price assumptions and other assumptions to estimate failure and preventive costs

Market and price assumptions	
Milk price (€ / kg milk)	0.41
Price of concentrates (€ / kg milk)	0.07
Costs antibiotics for treatment (€ / treatment)	22
Costs veterinary visits (€ / visit)	22
Costs labor (€ / h)	20
Costs of culled cow (€ / cow)	480
Other assumptions	
Milk production loss per case of CM (% of 2008 realized farm production)	5
Duration treatment (days)	3
Duration total withdrawal time (days)	6
Labor treatment (min / case)	45
Veterinary visits (% of cases)	5
Culling (% of clinical cases)	15
Milkings per day	2

The measures, derived from the questionnaire, were related to the prevention of the occurrence of mastitis and could be implemented on the farm on the short term. Measures were clustered in 4 categories: 1) the presence of a clean and dry comfortable environment, 2) a proper milking procedure, 3) a proper maintenance and use of milking equipment and 4) dry cow management. Management measures related to the presence of a clean and dry, comfortable environment were keep cow traffic areas clean and dry (clean lanes), keep cow lying areas clean and dry (clean cubicles) and ensure cows remain standing after milking by feeding and locking them with the feeding bars after milking (fixate cows after milking). Management measures related to proper milking procedures involved: pre-stripping all cows (pre-stripping), wear clean gloves during the milking process (milker's gloves), wash dirty udders before milking (wash dirty udders) apply post milking teat disinfectant (teat disinfectant) and milk cows with confirmed high SCC last (milk high SCC cows last). The measures related to proper management and use of milking equipment involved: thoroughly wash and sanitize clusters after milking a case of CM (rinse cluster after clinical case). The management measure related to dry cow therapy was use of antibiotics to dry off cows (drying off). An overview of the assumptions associated with each of the included management measures and the frequency with which each measure was applied by the farmer is provided in Table 2.

Costs estimates of all measures were based on the herd characteristics (e.g., number of dairy cows, CM incidence rate) combined with assumptions on price levels and technical input. Price levels were based on information from different suppliers and representative for 2015. Technical input was related to the amount of materials used, e.g. water for cleaning or disinfectant. When no information was available, the appropriate experts were consulted. For the measure 'clean lanes', labor costs were divided into labor necessary to start-up the measure and labor needed per cubicle. The measure 'clean cubicles' included labor costs and use of extra bedding material. 'Fixate cows after milking', included costs for installment of the feeding gate and labor to lock the cows directly after milking. The measure, 'pre-stripping' only included labor costs. The measure, 'milkers gloves' included the costs of buying gloves. 'Washing dirty udders', involved the costs and labor time to dry the udders, it was assumed that 5% of all cows had a dirty udder. The measure, 'teat disinfectant' included the costs of the use of the disinfectant and the labor for application. The measure, 'Milking high SCC cows last' included the labor to register cows with a high SCC (SCC > 250.000 cells /

mL) after each test-day date, the labor to separate high SCC cows before each milking and the investment of a separation fence. 'Rinsing a cluster after milking a clinical case', was assumed to include labor and water for cleaning. 'Drying off', included labor for application of antibiotics and the costs of antibiotics.

SENSITIVITY ANALYSIS

In our basic model, milk production losses caused by CM and SCM were estimated independent of each other. This, most probably, will be an over estimation of the total milk production losses, and thus failure costs, of mastitis. Therefore, in a sensitivity analysis, we estimated the FC assuming that milk production losses were only attributable to SCM. This would, most probably, lead to an underestimation of the total milk production losses. In addition, we estimated the total milk production losses in a scenario in which the SCM milk production losses were proportionally corrected, and CM milk production losses were assumed similar to those in the basic model. In this situation we assumed an overlap between SCM and CM milk production losses, as a part of the SCM cows are known to develop subsequent CM (van den Borne et al., 2010). For each farm the total SCM milk production losses were reduced with a farm specific proportion. This farm specific proportion was the number of cases of CM divided by the total number of cases of SCM on that farm. For instance, if 30 cases of CM were reported out of a total of 100 SCM cases, the milk production losses due to SCM would be reduced with a farm specific proportion of 0.3.

Table 2 Overview of the individual management measures and the corresponding assumed cost factors that serve as input for the cost estimation of the preventive costs. The observed application of the measure by each of 108 farmers is expressed in percentages and the estimated costs of the measures for those farmers that apply the measure in € / lactating dairy cow per yr.

	Assumed values	Observed application	Costs

Chapter 3

Measure	Cost factor	Assumption	Values	%	€ /cow / yr
Cleaning lanes	Start-up labor (min)	5	Never	18	0
	Labor per cubicle (min)	0.05	Once per day	82	14
Clean cubicles	Bedding material (€ / cow per yr)	3	Never	11	0
	Start-up labor (min)	5	Once per 2 days	1	13
	Labor per cubicle (min)	0.1	Once per day	48	23
			Twice per day	40	46
Fixate cows after milking	Labor (min / milking)	2	No	0	0
	Fence installment (€/yr)	250	Yes	100	10
Pre-stripping	Labor (min / milked cow)	0.08	Never	32	0
			Sometimes	22	10
			Always	45	19
Milkers gloves	Gloves (€/pair)	0.1	Never	39	0
			Sometimes	41	0.42
			Always	20	0.95
Wash dirty udders	Proportion of cows dirty	0.05	Never	78	0
	Water (L / cleaning)	2	Sometimes	15	5
	Price of water (€ / m^3)	1.2	Always	7	7
	Labor for drying (min / cleaning)	0.25			
Teat disinfectant	Labor (min / milked cow)	0.05	No	4	0
	Price of disinfectant (€ / 20L)	50	Dip	63	38
	Use of disinfectant (mL / milked cow)	5	Spray	33	21

Milking high SCC cows last	Separation fence (€ / yr)	200	Never	78	0
	Labor (min / milking)	5	Sometimes	12	11
	Labor identifying new high SCC cow (min / test-day record)	5	Always	10	19
Rinse cluster after clinical case	Labor (min / cleaning)	10	Never	36	0
	Water (L / cleaning)	10	Sometimes	47	15
			Always	17	29
Drying off	Antibiotics (€/cow)	12	No	9	0
	Labor (min/cow)	2	Yes	91	12

Economic assumptions on milk price and labor costs were expected to have a substantial impact on the total costs of mastitis. Whereas milk price only affects FC, labor costs affect both FC and PC. The total costs of mastitis were estimated with a high and low milk price of respectively, €31 / 100 kg milk and € 51 / 100 kg milk, and high and low labor costs of respectively, € 10 / h and € 30 / h.

4. RESULTS AND DISCUSSION

DESCRIPTIVE STATISTICS

Descriptive statistics of the 108 herds included in this study are presented in Table 3. The average herd size was 86 dairy cows which is greater than the Dutch average herd size of 75 dairy cows in the same period (CRV Year statistics, 2010). Inclusion criteria affected the average herd size directly and herds can generally be described as larger herds with a focus on udder health management. The average production of 27 kg milk / day was slightly greater than the Dutch average of 26.3 kg milk / day in 2008. The incidence rate of CM was 27% and average SCC was 192,000 cells / mL. Although farmers' reports on the number of CM cases could be over- or underestimated, we believe that, given the clear definition of CM, the experience of and the regular contact with the farmer, the farmers' reports on CM were as close as possible to the actual number of CM cases on the farm

On average, 9 test-day records were present for each cow. The method we used to estimate the milk production lacks the typical smooth lactation curve with a peak milk production in early lactation and levelling out in late lactation. Fitting individual lactation curves using a basic curve of Wood (1967) or more complex curves such as Rook et al. (1993) or Dijkstra et al. (1997) resulted in inconsistent parameters, because most dairy cows did not follow the assumed smooth lactation curve. Hence, we were not able to estimate reliable production curves on the individual cow level. In our study we were, however, interested in the milk production losses, the difference between the realized and potential milk production on a farm, and therefore decided that the interpolation method we used was sufficient, given the purpose of our study.

In our study we estimated average SCM milk production losses of 107 kg milk per lactating cow per yr. Other studies found SCM milk production losses to vary between 85 to 155 kg for first parity cows (Dürr et al., 2008; Halasa et al., 2009) and estimated average milk production losses of 445 kg of milk in multiparous cows (Hagnestam-Nielsen et al., 2009). The milk production losses, in our study, were assumed to occur when the SCC was > 50,000 cells / ml (Halasa et al., 2009). Thich is in line with the suggested threshold at which SCM milk production losses occur (Hortet and Seegers, 1998a). Despite this, the estimated milk production losses due to SCM were relatively low compared to other studies. This may have been a reflection of the herd health status of the study population. Alternatively, it may have been a consequence of the long-term involvement of farmers reporting mastitis problems from 2005 onwards and thus a better awareness of any mastitis problems.

The CM milk production losses were estimated at an average of 336 kg milk / case of CM. In a review of Hortet and Seegers (1998b) milk production losses associated with a case of CM were estimated to vary on average from 300 to 400 kg milk / case of CM. Nevertheless, in the same study, a large variation from 150 to 1,050 kg milk / lactation was found between cases of CM. Similarly, Hagnestam et al. (2007) showed that, within a lactation, the stage of lactation of a CM case strongly affected the magnitude of milk production losses. In our study, per farm, each case of CM had the same milk production losses. The natural variation in milk production losses between individual dairy cows on a farm was thereby neglected. In our study we were, however, interested in the milk production loss at farm level and not at the cow level, we therefore consider that our estimations were appropriate.

FAILURE COSTS

The average FC were €120 / lactating cow per yr (Table 4) with a minimum and maximum of respectively, €34 and €290 / lactating cow per yr. The average FC per case of CM was €301. CM contributed more to the total FC compared to SCM, €83 and €37 / lactating cow per yr, respectively. Milk production losses, discarded milk and culling contributed most to the FC of CM, respectively €32, €20 and €20 / lactating cow per yr. The FC of SCM were, on average, €37 / lactating cow per yr and varied between €15 and €65 / lactating cow per yr. Milk production losses, are invisible losses and may not be experienced as a cost factor by farmers. Although farmers may be aware of milk production losses due to mastitis, they may not know the economic impact of these (Huijps et al., 2008). Therefore, insights in these costs are valuable to farmers.

Costs of culling was a major contributor to the FC of CM. A disadvantage in our study was that we were not able to link CM cases to an individual cow in the test-day record data. It was, therefore, unknown to what extend culling could be associated with CM. Having this information would have led to a more accurate estimate of the expected economic value of an individual cow. Nevertheless, because reasons for culling are most often multifactorial (Bascom and Young, 1998), determining which cows were culled due to persistent mastitis problems would remain a difficult task.

Table 3 Description of the average herd characteristics of 108 Dutch dairy farms in which SCM milk production losses are determined as the difference between realized milk production and potential milk production and CM milk production losses as a fixed percentage of the average milk production per cow on a farm for each case of CM.

	Mean	Median	Min	Max
Lactating dairy cows (n)	86	80	50	325
Milk production loss SCM (kg / lactating dairy cow per yr)	107	81	7	262
Milk production loss CM (kg / case of CM per yr)	336	338	202	422
Incidence rate CM (% per yr)	27	25	2	82
SCC (x1,000 cells/ml)	192	81	73	378
Daily milk production (kg milk / day)	27	27	16	35

PREVENTIVE COSTS

Total PC were on average € 120 / lactating cow per yr of which labor costs were the main contributor (68%). The PC varied between €48 and €180 / lactating cow per yr. Out of the 10 preventive measures, derived from the questionnaire, 5 measures were from the top 10 most effective measures for either a 100% environmental or 100% contagious mastitis problem as found in the study of Hogeveen et al. (2011). Huijps et al. (2010) suggested a total of 18 measures to control mastitis, of which 10 were included in our study. The PC used in our study may underestimate the true PC because not all possible measures were included.

From the questionnaires, it was established that all farmers applied the measure 'fixate cows after milking' and that farmers applied, on average, 7 preventive measures. Only 2 farmers applied all 10 preventive measures. The average costs of each measure and the frequency of application are described in Table 2. The measures 'wash dirty udders' and 'milking high SCC cows last' were applied the least of all possible measures. The most often applied management measures were 'teat disinfection' (96%) and 'drying off' (91%). In our study we found a large variation in the applied preventive

strategies between farms. The decision to implement a specific combination of measures will, most likely, be based on multiple factors, e.g. perceived efficacy, costs estimation, herd situation, veterinary advice and personal preference. Taking all these factors into account makes that it is difficult for farmers to decide which combination of measures makes the optimal intervention strategy. As most farmers tend to not value their own labor (Huijps et al., 2008) they may be in need of a more proper economic guidance to come to a good decision on which measures to apply on their farm.

TOTAL COSTS OF MASTITIS

The total costs of mastitis were on average €240 / lactating cow per yr. A scatterplot of the total costs of mastitis for each farm is presented in Figure 1 in which each point in the graph represents the corresponding PC and FC for a farm expressed in € / lactating cow. The total costs of mastitis varied between €120 and €438 / lactating dairy cow per yr with a corresponding FC and PC of, respectively, €72 and €48 and €262 and €176 / lactating cow per yr. Because, in the study herds some level of clinical and subclinical mastitis always occurred, FC was calculated to be €34 / lactating cow per yr at the minimum. Due to this farmers will always apply preventive measures on their farm and PC will always occur, PC was calculated to be €48 / lactating cow per yr at the minimum.

A large variation in FC and PC between farms was found and in some cases farmers could have both a high FC and PC. It was expected that a relatively high PC would imply lower FC and vice versa (Hogeveen et al., 2011), but that

Table 4 Failure costs and prevention cost expressed in € / lactating cow per yr and split into five different scenarios: base scenario, low milk price scenario (€ 0.31 /kg milk), high milk price scenario (€ 0.51 /kg milk), low labor costs scenario (€ 10 /h) and high labor costs scenario (€ 30 /h) for each scenario all other costs remained equal to the average scenario.

Variable	Base scenario	Low milk price	High milk price	Low labor costs	High labor costs
Milk losses CM	32	23	42	32	32
Discarded milk	20	16	24	20	20
Veterinary visits	0.3	0.3	0.3	0.3	0.3
Labor	4	4	4	2	6
Antibiotics	6	6	6	6	6
Culling	20	20	20	20	20
Total CM	83	69	96	80	85
SCM production losses	37	26	48	37	37
Total failure costs	120	96	144	118	122
Labor	82	82	82	49	116
Consumables	34	34	34	34	34
Investments	4	4	4	4	4
Total prevention costs	120	120	120	87	154
Total costs mastitis	240	216	264	204	276

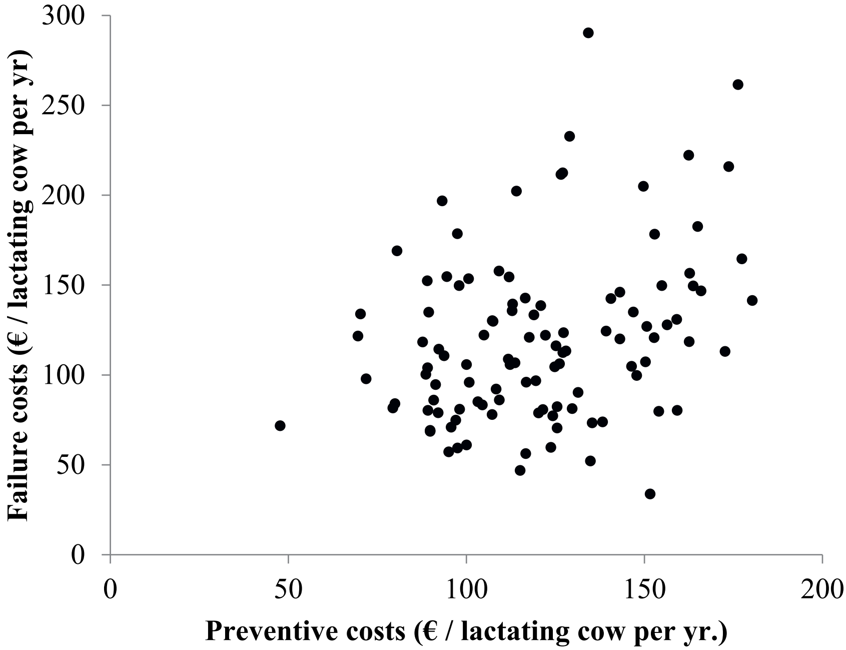

Figure 1 Estimated average preventive and failure costs associated with mastitis (€ / lactating dairy cow per yr) per herd. Each point represents an individual dairy farm (n=108).

was not observed in our study. The large variation between farms may be caused for different reasons such as differences in housing system, pasture access or milking systems. These structural differences between farms may limit the farmer in gaining a further reduction in FC when PC are increased. Secondly, farmers with a high incidence rate of CM or large amount of high SCC cows in their herd may be more likely to initiate preventive measures. Besides this the moment the preventive measure was implemented, might have influenced the magnitude of the effect of PC on FC, which may explain why herds with high PC may also have high FC. Farmers that initiated the preventive measure a longer time ago, could have already benefited from the PC investments via a reduction in FC. Third, there is a large variation in mastitis causing pathogens, leading to a large variation in severity and required therapy of CM cases in a herd (Wilson et al., 1999; Deluyker et al., 2005). A fourth explanation could be related to stockmanship and attitude, which results in a different application of the same preventive measures between farmers (Coleman et al., 1998; Seabrook and Wilkinson, 2000). Finally, although we included most measures (Dufour et al., 2011), we may be missing some mastitis management measures in our model such as for example adding appropriate minerals to the feed of dry-cows and replacing teat cup liners according to the manufacturer's norm. It was, however, not possible to include these measures in our study because the information on the applied measures were derived from a study performed earlier (Santman-Berends et al., 2012). Although the extra information could have been asked to the farmers again it is doubtful whether farmers would still remember the preventive measures applied in 2008.

A potential benefit of the preventive mastitis measures is that some measures may also improves the overall animal health status. Management measures that improve general hygiene such as cleaning cubicles and cleaning lanes could have had a, potential, positive effect on claw health status (Hultgren and Bergsten, 2001) and lower the FC of lameness. Given the interaction between mastitis, lameness, ketosis and reproductive disorders (Berge and Vertenten, 2014) a decrease in one of these diseases could result in a reduced risk of developing any of the other diseases. This suggests that the current model may underestimate the potential gains of a measures as FC only included the costs associated with mastitis. Ideally, exploring the total costs of any production disease as a construct of both FC and PC should be placed in a broader perspective in which the most common production diseases, e.g., mastitis, lameness, ketosis and reproductive disorders, and intervention strategies are included. Currently, good animal health information on all of these diseases, on farm level, together and the interaction between these diseases is hardly available. This makes that it is currently not possible to give a good farm specific estimate of the PC and FC of all these diseases.

Economic considerations are an important reason for farmers to implement changes on their farm. Given the substantial economic impact of mastitis, gaining insights in the FC and PC of mastitis is already useful information for farmers and veterinary advisors. Nowadays, most veterinary advisors have access to, relatively, good data on which mastitis prevention measures are applied on the farms and what the health status of a herd is with regard to mastitis. Therefore, they may be able to calculate the FC and PC for their clients and advice on how to improve their udder health management. Comparisons between farms could then lead to a discussion about economic costs and losses associated with mastitis together with the farmers' current management practice. An important reason for farmers' non-compliance with a veterinary herd health advice are the expected high costs and low returns (Derks et al., 2012). Although the veterinary advice costs were not included in the PC, in this study. Including the costs of veterinary advice costs in the PC puts the costs of veterinary advice in a perspective relative to the other applied management measures and may subsequently lead to a higher compliance of veterinary advice by farmers.

SENSITIVITY ANALYSIS

The use of test-day records and farm recordings to estimate the total costs of mastitis has some limitations. Including milk production losses due to both SCM and CM may have led to overestimations in our calculations. Moreover, the value of the major costs factors, labor costs and milk price, which were not available from the farms directly, rely on market price assumptions and can differ per farm.

In the basic model, milk production losses included both the losses due to SCM and CM. A scenario in which no milk production loss for a case of CM were assumed was expected to be on the low end of the milk production loss estimations. In this scenario the average FC were estimated at an average of €87 / lactating cow per yr with a minimum and maximum of respectively, €29 and €199 / lactating cow per yr. In the third scenario, SCM milk production losses were corrected, with a farm specific proportion and CM milk production losses were kept the same. This resulted in an average FC of €114 / lactating cow per yr with a minimum and maximum of respectively €33 and €272 / lactating cow per yr. Given that, to the authors' knowledge, no studies have reported the relation between SCC and CM regarding milk production losses or any carry-over effect between them. There is thus no certainty on whether assuming additional milk production loss of a case of CM is better compared to assuming no milk production loss at all or using a proportional correction. We believe that most reported cases of CM will likely not have been present at one of the test dates. Since milk delivered by cases of CM is typically withdrawn and at that time not recorded in the test-day records. Nevertheless, if the milk production losses would be assumed lower the losses due to mastitis were still substantial and, more important, the variation between farms remains large.

The costs estimate found in our study were higher compared to previous costs estimates on mastitis in the Netherlands which were made under the quota system (Huijps et al., 2009; Hogeveen et al., 2011). The total costs of mastitis were estimated for an average expected milk price, a low milk price (€ 31 / 100 kg milk) and a high milk price (€ 51 / 100 kg milk). The average FC in a low milk price scenario were €69 / lactating cow per yr and varied between €6 and €204 / lactating cow per yr. The average FC in a high milk price situation were €144 / lactating cow per yr and varied between €42 and €343 / lactating cow per yr. The milk price affects the costs of mastitis substantially and with an increasing milk price the need the improve the udder health status, and thereby reduce FC, will become more important.

Labor costs, affect both FC and PC. The value of labor was not available for individual farms, the labor costs for a base situation, a situation with low labor costs (€ 10 / h) and a situation with high labor costs (€ 30 / h) were evaluated to gain insights in the effect of labor costs on the total costs of mastitis. As both preventive measures and treatment of cows suffering from mastitis involve labor, both PC and FC were affected when labor costs changed. On herd level, high labor costs were associated with an average total cost of mastitis of €276 / lactating cow per yr and varied between €131 and €510 / lactating cow per yr. Low labor costs were associated with an average total cost of mastitis of €204 / lactating cow per yr and varied between €108 and €371 / lactating cow per yr. Given that labor was the most important factor in PC, it is important for farmers to value their own labor. As mentioned earlier, wrong estimates of own labor may affect the decision-making process on a farm.

The assumptions for labor costs and milk price influenced the total costs of mastitis substantially. Although, the absolute levels of FC and PC may vary depending on the assumptions made, our conclusion that there is a large amount of variation in economic costs associated with mastitis between farmers, and thus room for improvement, remains valid. It thus remains important for farmers to gain insights in their personal economic situation regarding mastitis, to gain insights in where the costs of mastitis can, potentially, be further reduced.

5. CONCLUSION

Total costs of mastitis that were based on the combination of PC and FC were estimated at, €240 / lactating cow per yr. A minimum amount of loss due to FC and minimum amount of PC, associated with mastitis would always occur. Furthermore, a large variation in the total costs of mastitis was found between farms, which may indicate that farmers can improve their economic situation with regard to mastitis control.

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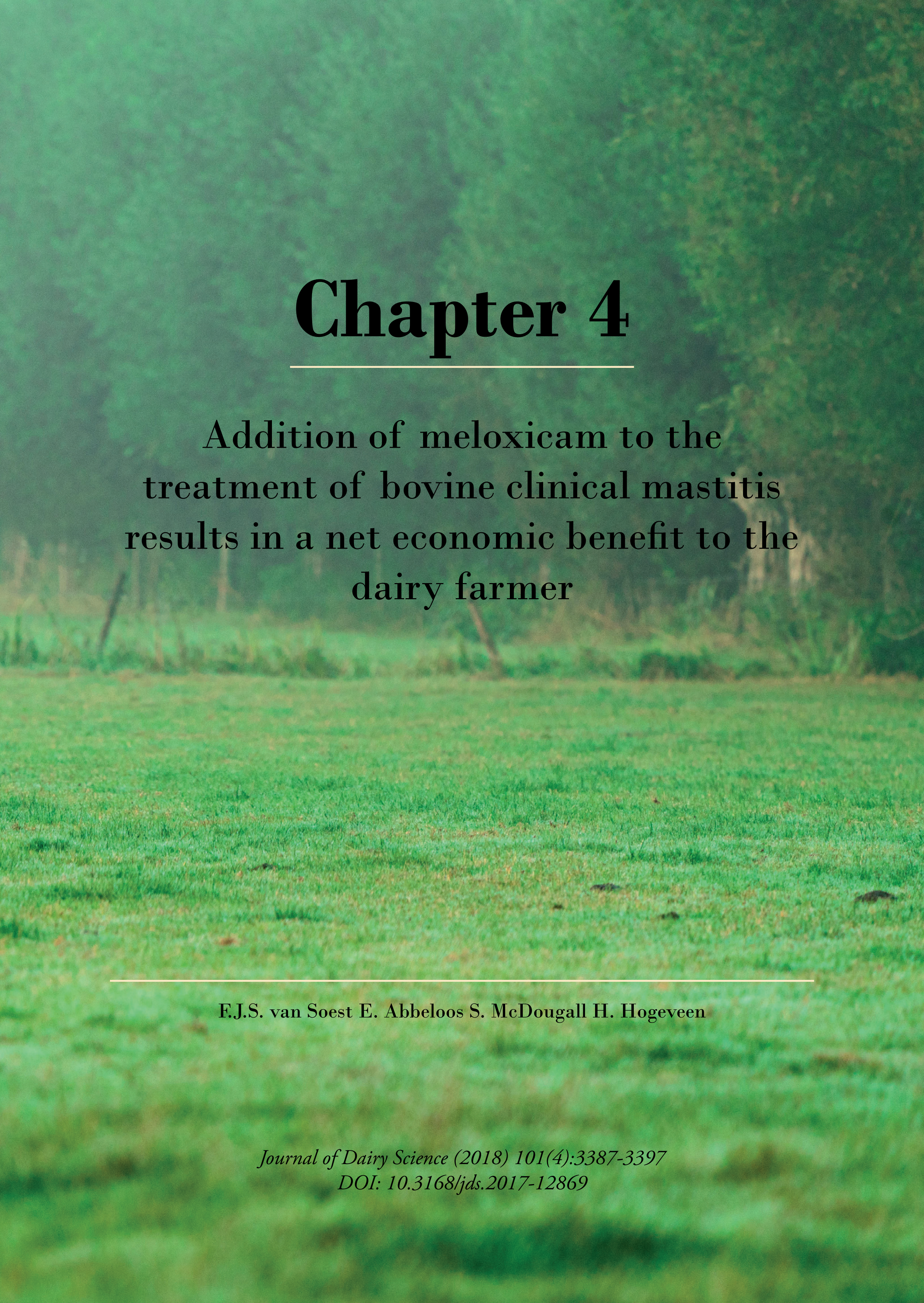

Chapter 4

Addition of meloxicam to the treatment of bovine clinical mastitis results in a net economic benefit to the dairy farmer

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1. ABSTRACT

Recently, it has been shown that the addition of meloxicam to standard antimicrobial therapy for clinical mastitis (CM) improved the conception rate of dairy cows contracting CM in the first 120 days in milk. The objective of our study was to assess whether this improved reproduction through additional treatment with meloxicam would result in a positive net economic benefit for the farmer. We developed a stochastic bio-economic simulation model, in which a dairy cow with CM in the first 120 days in milk was simulated. Two scenarios were simulated in which CM cases were treated with meloxicam in conjunction with antimicrobial therapy, or with antimicrobial therapy alone. The scenarios differed for conception rates (31% with meloxicam or 21% without meloxicam) and for the cost of CM treatment. Sensitivity analyses were undertaken for the biological and economic components of the model, to assess the effects of a wide range of inputs on the inferences about the cost effectiveness of meloxicam treatment. Model results showed an average net economic benefit of € 42 per CM case per year in favor of the meloxicam scenario. Although cows in the non-meloxicam treatment scenario had higher returns on milk production, lower costs upon calving and reduced costs of treatment; these did not outweigh the gains in lower feed intake, reduced number of insemination and the reduced culling rate. The net economic benefit favoring meloxicam therapy was a consequence of the better reproductive performance in the meloxicam scenario in which cows had a shorter calving to conception interval (132 vs. 143 d), a shorter inter-calving interval (405 vs. 416 d) and fewer AI per conception (2.9 vs. 3.7) compared to cows in the non-meloxicam treatment scenario. This resulted in a shorter lactation, hence a lower lactational milk production (8,441 vs. 8,517 kg per lactation) with lower feeding costs in the meloxicam group. A lower culling rate (12% vs. 25%) resulted in lower replacement costs in the meloxicam treatment scenario. All of the scenarios evaluated in the sensitivity analyses favored meloxicam treatment over no meloxicam treatment. This study demonstrated that

improvements in conception rate achieved by the use of meloxicam, as additional therapy for mild to moderate CM in the first 120 days in milk, have positive economic benefits. This inference remained true over a wide range of technical and economic inputs, demonstrating that use of meloxicam is likely to be cost-effective across many production systems.

2. INTRODUCTION

Bovine clinical mastitis (CM) is a disease which has important consequences for farmers globally. Besides compromised cow welfare, it incurs economic losses through cost of treatment, production loss and withdrawal of milk (Hogeveen et al., 2011). In addition, CM impairs reproductive performance, including a longer interval from calving to conception, more services per conception (Barker et al., 1998; Schrick et al., 2001), lower conception rates (Santos et al., 2004; Lavon et al., 2011), and a higher risk of embryo loss (Chebel et al., 2004; McDougall et al., 2005).

In a blinded, negative controlled, randomized intervention study carried out in 6 European countries, it was found that the addition of meloxicam, a nonsteroidal anti-inflammatory drug, to antimicrobial treatment of mild to moderate CM improved fertility in dairy cows (McDougall et al., 2016). Treatment with meloxicam was associated with a higher proportion of cows conceiving at their first artificial insemination (0.31 versus 0.21), and a higher proportion of meloxicam-treated cows becoming pregnant by 120 d after calving (0.40 versus 0.31). The number of artificial inseminations required to achieve conception was lower in the meloxicam treated cows compared with the control cows (2.43 versus 2.92).

Fertility is an important factor in herd economics; it was therefore hypothesized that the improvements in fertility associated with treatment of mastitis with meloxicam would have an impact on profit. A stochastic calculation of the costs and benefits of treating mastitic cows with meloxicam would aid decision making at the individual cow level for a specific case of mastitis on a specific farm. Contrary to deterministic models that make definite predictions for quantities, a stochastic model, containing probability distributions, accounts for the uncertainty in the behavior of a system. This has the distinct advantage that individuals can be handled differently, whereby each simulation run contains animals with different performances in production and reproduction. Deterministic models do not account for such variation between individuals which results in an oversimplification of the reality under which decisions need to be made (Dijkhuizen and Morris, 1997).

Previously developed stochastic models (Inchaisri et al., 2010; Rutten et al., 2014) have already assessed the economic consequences of reproductive performance in dairy cows. In those models, individual dairy cows were simulated in weekly time steps, in which all biological relevant events occur, which are milk production, reproductive performance, feed intake and herd removal. In these models, increased calving interval, involuntary culling and the return of milk production were found to have the largest influence on the cost of reproductive efficiency. The objective of the current study was to assess whether the improved reproduction outcomes of treatment of CM with meloxicam, would result in a positive net economic benefit for the farmer.

3. MATERIAL AND METHODS

MODEL SPECIFICATION

We developed a stochastic dynamic simulation model to explore the economic consequences of improved reproductive performance in dairy cattle, diagnosed with mild to moderate CM in the first 120 days in milk and treated with meloxicam in addition to antibiotic treatment. The basic properties of the model were copied from the model of Inchaisri et al. (2010) where a dairy cow was simulated in weekly time steps during one randomly assigned parity. During each iteration all the biologically relevant events of a parity of a dairy cow were simulated from calving to either the next calving or culling. The biological events included the simulation of the reproductive cycle, milk production and occurrence of CM. Occurrence of CM was specifically developed for the purpose of this study together with the effects of CM on the other biological events. First, the elements that have been copied from Inchaisri et al. (2010) will be briefly explained, second the specifics of CM occurrence and the effects on other biological events will be explained in detail.

Existing model specifications: reproductive cycle, milk yield and feed intake. The reproductive cycles included ovulation, estrus detection, insemination, conception and calving. Ovulation was simulated from calving onwards and followed a lognormal distribution. The ovulation interval was assumed to be at least 3 weeks but could be delayed depending on the occurrence of postpartum disorders. The probability of estrus detection following ovulation was corrected for milk yield. Artificial insemination (AI) occurred when estrus was detected, and the voluntary waiting period was exceeded. The probability of conception in each iteration depended on the base conception risk (CR) of the scenario and was corrected for milk production level, parity, days in milk and occurrence of postpartum disorders other than CM. If insemination was unsuccessful, the process of ovulation, estrus detection and insemination continued. Some cows were considered to face embryonic death after an initial successful conception, which prolonged the reproductive cycle for a period of 6 - 8 weeks before normal cyclicity started again. The gestation length varied between 39-41 weeks, following a uniform distribution. The week of drying off was fixed at week 33 after successful conception, so that the dry period length (DPL) varied between 6 - 8 weeks (Table 1). As a result of the stochastic simulation of the fertility events, each parity ends in week n, which is the length of the lactation plus DPL. For non-pregnant cows, logically, no dry period was required at the end of parity and week n was based on set culling rules. The culling rules were adapted from Rutten et al. (2014). Cows were eligible for herd removal when either after 7

Table 1 Description of input parameters, corresponding values, abbreviations and reference sources

Description	Value	Abbreviations	References
Herd milk production (kg milk)	8,310	HMP	CRV (Dutch Royal Cattle Syndicate, 2015)
Voluntary waiting period (wks)	9	VWP	Rutten et al. (2014)
Culling rules			
Max AI (# per lactation)	7		Rutten et al. (2014)
Cows are culled when milk production drops below (kg milk / d)	15		Rutten et al. (2014)
Dry period length	Uniform (6, 8)	DPL	
Conception risk (CM, no meloxicam)	0.21	CR^{nm}	McDougall et al. (2016)
Conception risk (CM, meloxicam)	0.31	CR^{m}	McDougall et al. (2016)
Week of occurrence of CM	Round(betageneral(1.25,1.5,1,17),0)	WIM^{CM}	McDougall et al. (2016)
Milk production at CM occurrence	Uniform(15%,18%)	MPL^{max}	McDougall et al. (2009)
Performance index lactation	Normal (1,0.1)	PI	Inchaisri et al. (2010)
Costs price assumptions			
Milk price (€ / kg milk)	0.32	P^{milk}	Rutten et al. (2014)
Feed price (€ / VEM)[1]	0.16	P^{feed}	Vermeij (2012)
Treatment costs (€ / treatment)	33.50	P^{trtm}	Manufacturer's norm
Additional use meloxicam (€ / treatment)	15	P^{mxc}	Manufacturer's norm

Calving costs (€/ calf)	152	$P^{calving}$	Vermeij (2012)
Revenue sold calf (€ / calf)	100	P^{calf}	Vermeij (2012)
Retention Pay-off values (€ / culled cow)			Inchaisri et al. (2010)
Parity 1	-1,265.41 + 1,730 x PI	RPO^{p1}	
Parity 2	-1,511.93 + 2,133 x PI	RPO^{p2}	
Parity 3	-1,453.09 + 2,080 x PI	RPO^{p3}	
Parity 4	-1,384.01 + 1,983 x PI	RPO^{p4}	
≥Parity 5	-1,309.77 + 1,864 x PI	RPO^{p5}	

[1] Feed requirements estimated as energy requirements in feed units for lactation (VEM; 1,000 VEM = 1 kVEM = 1,650 kcal) as defined by van Es (1978)

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inseminations no successful insemination occurred or a cow did not have a successful conception at week 42 after calving. Non-pregnant cows were removed when their daily milk yield dropped below 15 kg milk per day. The length of parity for each iteration is thus variable and depends on the pregnancy status.

The potential milk production of any given cow depended on the average herd milk production and was corrected for the individual cows' performance index (PI) during the lactation (a value from 0.9 to 1.1 drawn from a normal distribution), and parity (randomly drawn from the parity distribution). The potential milk production was used to determine the average daily milk yield (MYi) per week i, based on the Wood function (Wood, 1967). The weekly milk yield was corrected for conception status, occurrence of CM and days in milk. Milk production stopped at either the date of drying off or at the moment of culling.

The weekly feed requirements were estimated based on the weekly milk yield and expressed as the required energy in feed units for lactation (VEM) as defined by Van Es (1978). One feed unit of VEM equals 1.65 kcal of energy and 1,000 VEM equals 1 kVEM. The weekly kVEM were influenced by milk production, pregnancy status and dry period.

Development of CM model additions and adaptations to existing model. Consistent with McDougall et al., 2016, cows in our model were considered to have an episode of mild to moderate mastitis within the first 120 days in milk. Mild to moderate cases were defined as cows diagnosed with apparent changes in the milk and/or local inflammation in the mammary gland but without systemic symptoms (Erskine et al., 2003).The existing models described above were adjusted such that all biologically relevant events associated with CM were included: the risk of conception, milk production loss and discarded milk. Model input is presented in Table 1. Consequently, two treatment scenarios were simulated: first a scenario where meloxicam was used as additional treatment for CM and second a scenario where no meloxicam was used. The tested scenarios are an economic continuation of the findings found by McDougall et al. (2016) in which meloxicam treated cases of CM had a higher CR compared to non-meloxicam treated cases of CM (0.31 vs. 0.21). The model and simulations were developed and performed in Microsoft Excel (Microsoft Corporation, Redmond, WA, USA) using the @Risk add-in software (Palisade Corporation, Ithaca, NY, USA) for the stochastic properties of the model. For each analysis, a total of 50,000 iterations were run. More in-depth model specification regarding the components that have been developed previously can be found in Inchaisri et al. (2010) and Rutten et al. (2014). The adjustments and additions to the previous models are described in more detail in the following sections.

Base Conception Risk. In the non-meloxicam treatment scenario, the base CR was set at 0.21 for CM cases and in the meloxicam treatment scenario at 0.31 for CM cases (McDougall et al., 2016). The probability of a successful conception gradually increased in weekly time steps.

Clinical Mastitis. For each lactation the week in which CM occurred (WIMCM) was modelled following a beta distribution (Table 1) such that all cases occurred within the first 17 weeks of lactation (119 days) and the majority of cases occurred within the first weeks of lactation.

For each week i, the actual daily milk yield (MY_i^{act}) was based on the daily milk yield from the Wood function (MY_i) after correction for the occurrence of CM. The occurrence of CM was associated with an initial drop in daily milk yield commencing one week prior the WIM^{cm}. The (MY_i^{act}) was estimated using equation [1].

$$MY_i^{act} \begin{cases} if\ i = WIM^{CM} - 1 \rightarrow MY_i - (MY_i \times MPL^{\max} \times 0.75) \\ if\ i = WIM^{CM} \rightarrow MY_i - (MY_i \times MPL^{\max}) \\ if\ i > WIM^{CM}\ and\ MY_{i-1} - MY_{i-1}^{act} > 0.015 \rightarrow MY_i - [(MY_{i-1} - MY_{i-1}^{act}) \times 0.89] \\ else\ MY_i \\ i = 1, \ldots\ldots, n \end{cases} \quad [1]$$

In equation [1] production losses were associated with CM and expressed as a percentage of MY_i. At WIM^{CM} the production loss was at a maximum (MPL^{max}) and drawn from a uniform distribution (Table 1). The loss prior to WIMCM starts with 75% of the MPL^{max}. The weeks following WIM^{cm} milk yield losses decreased gradually (McDougall et al., 2009) with 89% of the milk production loss in the preceding week. Once milk production loss in the preceding week was < 0.015 kg milk day, then MY_i^{act} was assumed to equal MY_i.

In both treatments, CM was treated with an antibiotic therapy, as a consequence milk had to be discarded during a withdrawal period of 5 days directly following treatment. The volume of the discarded milk (MY_i^{disc}) was estimated using equation [2]

$$MY_i^{disc} \begin{cases} if\ i = WIM^{CM} \rightarrow MY_i^{act} \times 5 \\ else\ 0 \\ i = 1,.....,n \end{cases} \qquad [2]$$

In equation [2] MY_i^{disc} was estimated as the total amount of kg milk discarded at week i. Milk withdrawal was assumed to occur at WIM^{CM} and the amount of milk withdrawn was assumed to equal MY_i^{act} at WIM^{CM} multiplied with the assumed withdrawal period.

For each iteration the total amount of milk produced was summed (MP^{total}). MP^{total} was simulated using the equation [3].

$$MP^{total} = \left(\sum_i^n MY_i^{act} \times 7 - MY_i^{disc} \right) \qquad [3]$$

In equation [3] the MP^{total} is the total amount of MY_i^{act} minus MY_i^{disc} produced during one iteration.

ECONOMIC OUTPUT

For each iteration in both treatment scenarios, the net cash flow (NCF) was estimated, resulting in 50,000 estimates of NCF for either treatment scenario. The net cash flow was estimated using equation [4]. The NCF was calculated based on costs and benefits associated with the technical parameters at the end of each iteration. These technical parameters included: the total milk production during the lactation expressed in kg milk (MP^{total}), the total feed intake expressed in kVEM (FI), the total number of AI (AI), the final conception status (SCO) set to one after a successful conception else assumed zero and culling status (SCF) set to one after herd removal else assumed zero. Both SCO and SCF were binary events, meaning that the event either occurred or did not occur, meaning that costs only occurred once the event took place.

$$NCF = \frac{MP^{total} \times P^{milk} + FI \times P^{feed} + P^{trtm} + AI \times P^{AI} + SCO \times (P^{calf} - P^{calving}) + SCF \times P^{RPO}}{DIP} \times 365 \qquad [4]$$

The numerator of equation [4] represents the cash flow for an individual dairy cow in her respective parity. Due to the stochasticity of the fertility events, each iteration results in a different parity length, expressed in days in parity (DIP). Consequently, the numerator was divided by DIP and multiplied by 365 to standardize results per cow per year and make the NCF comparable between and within treatment scenarios.

NCF included the following economic parameters: the price of milk (Pmilk), costs of feed (P^{feed}), costs of treatment (P^{trtm}), costs of AI (P^{AI}), calf price (P^{calf}), calving management costs ($P^{calving}$) and retention pay off-value depending on parity number p (P^{RPO}) the assumed price levels are given in Table 1. The Retention Pay Off (RPO) values accounts for any future profit that would be made if the cow was kept until her optimal milk production compared with the immediate cost and benefit of replacement of the animal (Dijkhuizen and Morris, 1997; Inchaisri et al., 2010). The majority of the price assumptions were similar to Inchaisri et al. (2010) with the exception of P^{milk} and P^{feed} which were based on Rutten et al. (2014) and assumed € 0.32 per kg milk and € 0.17 per kVEM. Treatment costs of a case of CM were assumed to be € 48.50 for treatment with or € 33.50 for treatment without meloxicam. The net economic benefit was the difference between the average NCF between both model scenarios, without and with meloxicam.

SENSITIVITY ANALYSIS

A technical sensitivity analysis was performed in order to represent a wide variety of management systems in Europe. Sensitivity of the model to the following parameters was tested: average milk production, estrus detection rate, production threshold at which non-pregnant cows are culled, voluntary waiting period, average conception risk and maximum number of AI per cow. Also, a change in percentage milk production loss due to CM was calculated in this technical analysis. An economic sensitivity analysis was performed to explore the net economic benefit in changing market situations: impact of milk price and feed cost, RPO, and cost of insemination. The impact of milk price (€ per kg milk) and feed costs (€ per kVEM) were determined using the milk-feed price ratio (MFR). The MFR is the ratio between milk price and feed price. A high MFR thus represents a larger margin on the revenues compared to a situation with a low MFR. The MFR situations were based on the lowest and highest recorded long term milk prices across the EU (Eurostat, 2016). Three MFR values, 1, 2, and 3, were used to determine the corresponding feed price and margin. Each of the MFR corresponded to a low milk price (MP) of €0.15 per kg milk, medium MP of €0.32 per kg milk and high MP of €0.47 per kg milk, resulting in a total of 9 potential MFR scenarios. For example, a medium milk price and a MFR of 2 means that feed price equals €0.16 per kVEM. Model validity was checked using the rationalism method and face validity (Sørensen, 1990).

4. RESULTS

TECHNICAL OUTPUT

Model results showed that the average milk yield per lactation was estimated at 8,441 (5th-95th percentile; 6,444 – 10,596) kg milk in the meloxicam treatment scenario vs. 8,517 (5th-95th percentile; 6,507 – 10,641) in the non-meloxicam treatment scenario (Table 2). Reproductive performance was better in the meloxicam than in the non-meloxicam treatment scenario. The average number of AI was 2.9 (5th-95th percentile; 1 - 7) vs. 3.6 (5th-95th percentile; 1 - 7), calving to conception interval was 132 d (5th-95th percentile; 56 - 252) vs. 143 d (5th-95th percentile; 63 - 259) and calving interval was 405 d (5th-95th percentile; 329 - 525) for the meloxicam treatment scenario vs. 416 d (5th-95th percentile; 336 - 532) for the non-meloxicam treatment scenario. In both scenario's, 53% of all cows had a first insemination within 3 weeks after the VWP and first service occurred on average 80 (5th-95th percentile; 56 - 126) days after calving. The percentage of dairy cows that were non-pregnant and therefore culled was 12% in the meloxicam treatment scenario and 25% in the non-meloxicam treatment scenario.

Discriminating technical output for pregnancy status shows that pregnant cows in the meloxicam scenario have a lower average milk production per lactation compared to pregnant cows in the non-meloxicam treatment scenario, 8,443 (5th-95th percentile; 6,426 – 10,622) vs. 8,572 (5th-95th percentile; 6,525 – 10,723) kg milk. The average calving interval in the meloxicam treatment scenario was 405 days (5th-95th percentile; 329 - 528) vs. 416 days (5th-95th percentile; 336 - 532) in the non-meloxicam treatment scenario. Conversely, non-pregnant cows in the meloxicam scenario had a higher milk production than non-pregnant cows in the non-meloxicam scenario; 8,422 (5th-95th percentile; 6,557 – 10,421) vs. 8,350 (5th-95th percentile; 6,470 – 10,402) kg milk (Table 3). Non-pregnant cows had a calving to culling interval of 328 days for both treatment scenarios. Non-pregnant cows received more AI during a lactation, 5.6 (5th-95th percentile; 3 – 7) and 5.9 (5th-95th percentile; 3 – 7), compared to pregnant cows, 2.5 (5th-95th percentile; 1 – 6) and 2.9 (5th-95th percentile; 1 – 6), for the meloxicam and non-meloxicam treatment scenarios respectively.

Table 2. Modelled mean (5th and 95th percentile between parentheses) of reproductive and productive outcomes per lactation for cows with CM which were either treated with or without meloxicam in addition to routine antimicrobial therapy

	Meloxicam	Non-meloxicam
Number of AI per pregnant cow (no.)	2.5 (1 – 6)	2.9 (1 – 6)
Number of AI per cow (no.)	2.9 (1 – 7)	3.6 (1 – 7)
Calving to conception interval (d)	132 (56 – 252)	143 (63 – 259)
Calving to first service interval (d)	80 (56 – 126)	80 (56 – 126)
Calving interval (d)	405 (329 – 525)	416 (336 – 532)
Bred within 3wks after VWP (%)	53%	53%
Days in parity (d)	396 (315 – 518)	394 (301 – 525)
Milk production per cow per lactation (kg)	8,441 (6,444 – 10,596)	8,517 (6,507 – 10,641)
Feed intake per cow (x 1,000 kVEM)[1]	620 (497 – 767)	619 (484 – 772)
Cows culled for fertility reasons (%)	12%	25%

[1] Feed requirements estimated as energy requirements in feed units for lactation (VEM; 1,000 VEM = 1 kVEM = 1,650 kcal) as defined by van Es (1978)

Table 3 Modelled mean (5th and 95th percentile between parentheses) of reproductive and productive outcomes per lactation for cows with CM, differentiated for pregnancy status, which were either treated with or without meloxicam in addition to routine antimicrobial therapy

	Meloxicam		Non-meloxicam	
	Pregnant	Non-pregnant	Pregnant	Non-pregnant
Number of AI per cow (no.)	2.5 (1 – 6)	5.6 (3 – 7)	2.9 (1 – 6)	5.9 (3 – 7)
Calving to conception interval (d)	132 (56 – 252)		143 (63 – 259)	
Calving to first service interval (d)	79 (56 – 126)	85 (56 – 140)	79 (56 – 126)	84 (56 – 140)
Bred within 3wk after VWP (%)[1]	54%	47%	54%	49%
Calving interval (d)	405 (329 – 525)		416 (336 – 532)	
Calving to culling (d)		328 (294 – 392)		328 (294 – 392)
Milk production per cow per lactation (kg)	8,443 (6,426 – 10.622)	8,422 (6,557 – 10,421)	8,572 (6,525 – 10,723)	8,350 (6,470 – 10,402)
Feed intake per cow (x 1,000 kVEM)[2]	6,281 (5,101 – 7,711)	5,565 (4,567 – 6,723)	6,400 (5,155 – 7,820)	5,531 (4,533 – 6,684)

[1] VWP = Voluntary waiting period

[2] Feed requirements estimated as energy requirements in feed units for lactation (VEM; 1,000 VEM = 1 kVEM = 1,650 kcal) as defined by van Es (1978)

ECONOMIC OUTPUT

The returns on sold milk were larger in the non-meloxicam treatment scenario compared to the meloxicam treatment scenario: €2,562 against €2,520 / CM case per yr. The largest cost factor was feed cost, which was slightly lower for the meloxicam treatment: €931 against €935 / CM case per yr. The average total feed intake in absolute levels per lactation was higher in the meloxicam treatment scenario (6,195 vs 6,190 x 1,000 kVEM), nevertheless when economic results were standardized to € per case of CM per year, the total costs of feed were lower (Table 4) which was due to the slightly longer length of lactation in the meloxicam treatment scenario (396 vs. 394 days). Largest costs differences between both scenarios were found in AI (€80 vs. €103 per CM case per yr) and culling costs for non-pregnant cows, which were both lower in the meloxicam treatment scenario (€78 vs. €157 per CM case per yr). Both were a consequence of the better reproductive performance in the meloxicam treatment scenario which resulted in less fertility related culling. The net cash flow for the meloxicam treatment scenario was €1,343 per CM case per year (5th-95th percentile; €957 - €1,796) and €1,300 (5th-95th percentile; €947 - €1,768) per CM case per yr in the non-meloxicam treatment scenario. The average net economic benefit was thus €42 per CM case per yr in favor of the meloxicam treatment scenario (difference due to rounding) (Table 4). The cumulative density distribution presented in Figure 1 showed that for both treatment scenarios the net cash flow had a normal distribution and an overall better performance for meloxicam treated cases of CM.

Discriminating economic output for pregnancy status shows that the net cash flow is higher for the pregnant cows in the meloxicam scenario €1,376 (5th-95th percentile; €973 - €1,811) vs. €1,364 (5th-95th percentile; €963 - €1,802) per CM case per year in the non-meloxicam scenario. The difference between non-pregnant cows in both scenarios was small: €1.101 (5th-95th percentile; €930 - €1,289) in the meloxicam treatment scenario against

€1,106 (5th-95th percentile; €937 - €1,300) per CM case per year in the non-meloxicam treatment scenario (Table 5).

SENSITIVITY ANALYSIS

Model results of the technical sensitivity analysis are presented in Figure 2 and those of the economic sensitivity analysis are presented in Figure 3. Results are presented as net economic benefit and the base results, €42 / CM case per yr, was set as reference line.

Technical Sensitivity Analysis. Results of the technical sensitivity analysis showed that all scenarios favor the meloxicam treatment scenario. The net cash flow was always largest for the meloxicam treatment scenario compared to the non-meloxicam treatment scenario, resulting in a positive net economic benefit. A relative low milk production per cow (6,000 kg milk / 305d) and increased waiting time to cull non-pregnant cows (milk production at culling 10 kg milk / d) increase net economic benefit substantially: €59 and €54 / CM case per yr, respectively. Whereas an average estrus detection rate of 30% (base model 50%) and reduced CR (CR 0.15 with and 0.1 without meloxicam treatment) decreased the net economic benefit to € 31 and € 32 / CM case per yr, respectively. Increasing voluntary waiting period from 9 to 15 weeks resulted in a net economic benefit of €32 / CM case per yr.

Economic Sensitivity Analysis. Similar to the technical sensitivity analysis, model results on net economic benefit favored the meloxicam treatment scenario in all the economic sensitivity analysis scenarios. A decreasing milk price, increasing insemination costs or increasing retention to pay off value, increase net economic benefit in favor of the meloxicam treatment scenario. Whereas, an increasing milk price, lower insemination costs and reduced retention to pay off value, decrease net economic benefit. A high milk price in combination with a MFR of 3, resulted in a net economic benefit of € 18 / CM case per yr, which was the lowest average net economic benefit

Table 4 Economic results presented as the different cost factors and net cash flow for an average case of CM with or without an additional treatment with meloxicam (5th and 95th percentile between parentheses). The net economic benefit is the difference between meloxicam treated cases and non-treated cases. Values are presented in a standardized € / CM case per yr to make results comparable

	Meloxicam	Non-meloxicam	Net economic benefit
Milk production	2,520 (1,967 – 3,194)	2,562 (1,965 – 3,294)	-42
Feed intake	-931 (-1,067 – -812)	-935 (-1,075 – -810)	3
AI	-80 (-207 – -29)	-103 (-243 – -30)	24
Calving	-42 (-58 – 0)	-35 (-56 – 0)	-7
CM treatment	-46 (-56 – -34)	-32 (-41 – -23)	-14
Replacement	-78 (-699 – 0)	-157 (-824 – 0)	79
Net cash flow	1,343 (957 – 1,756)	1,300 (947 – 1,768)	42

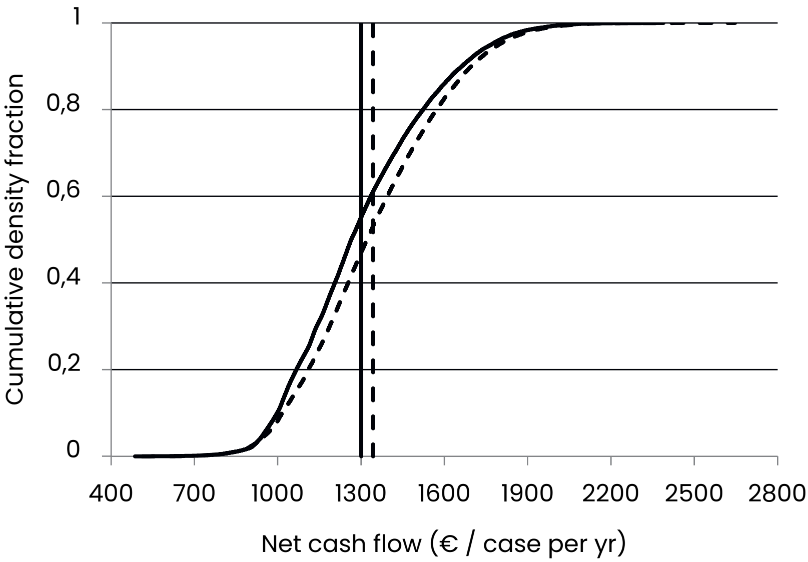

Figure 1. Cumulative density distribution of the net cash flow for the meloxicam (dotted line) and non-meloxicam (solid line) treatment scenario, vertical lines represent the average values for both treatment scenarios

Table 5 Economic results differentiated for pregnancy status and presented as the different cost factors and net cash flow for an average case of CM with or without an additional treatment with meloxicam (5th and 95th percentile between parentheses). Values are presented in a standardized € / CM case per yr to make results comparable. Any differences in net cash flow are due to rounding.

	Meloxicam	Non-meloxicam	Net economic benefit
Pregnant			
Milk production	2,455 (1,952 – 3,005)	2,427 (1,929 – 2,977)	27
Feed intake	-922 (-1,047 – -808)	-915 (-1,040 – -801)	-7
AI	-65 (-127 – -29)	-73 (-137 – -30)	8
Calves	-48 (-58 – -36)	-47 (-56 – -36)	-1
CM treatment	-45 (-54 – -34)	-30 (-36 – -23)	-15
Net cash flow	1,376 (973 – 1,811)	1,364 (963 – 1,802)	12
Non-pregnant			
Milk production	2,997 (2,447 – 3,507)	2,976 (2,432 – 3,496)	21
Feed intake	-1,001 (-1,115 – -886)	-997 (-1,112 – -882)	-5
AI	-188 (-261 – -100)	-198 (-261 – -109)	9
CM treatment	-54 (-60 – -45)	-38 (-42 – -31)	-17
Non-pregnant cows	-652 (-1,000 – -325)	-638 (-984 – -299)	-14
Net cash flow	1,101 (930 – 1,289)	1,106 (937 – 1,300)	-5

Chapter 4

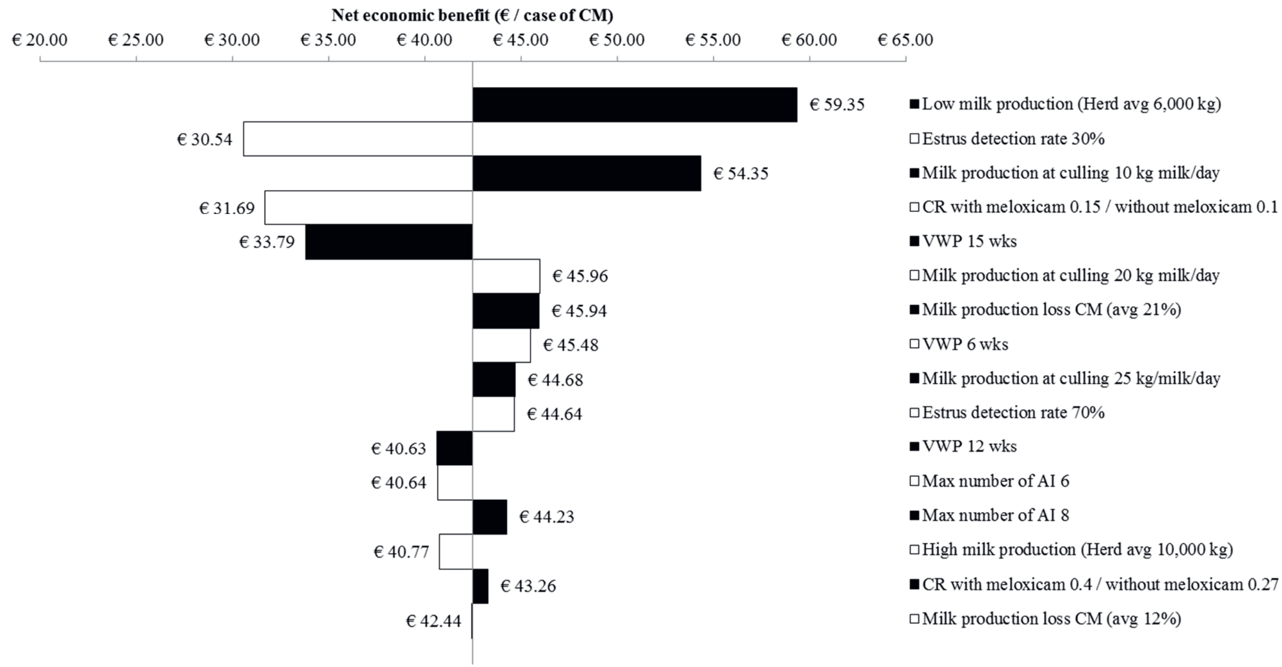

Figure 2. Tornado graph of the net economic benefit of meloxicam treatment versus no meloxicam treatment (€ / case of CM) when the value of the single technical input parameters (estrus detection, conception rate (CR), voluntary waiting period (VWP), milk production loss associated with a case of CM at the moment of acquiring mild CM, maximum number of artificial inseminations (AI) for each cow per parity and the moment a cow is removed (due to non-pregnancy) from the herd once milk production drops below a certain threshold) were changed in both scenarios

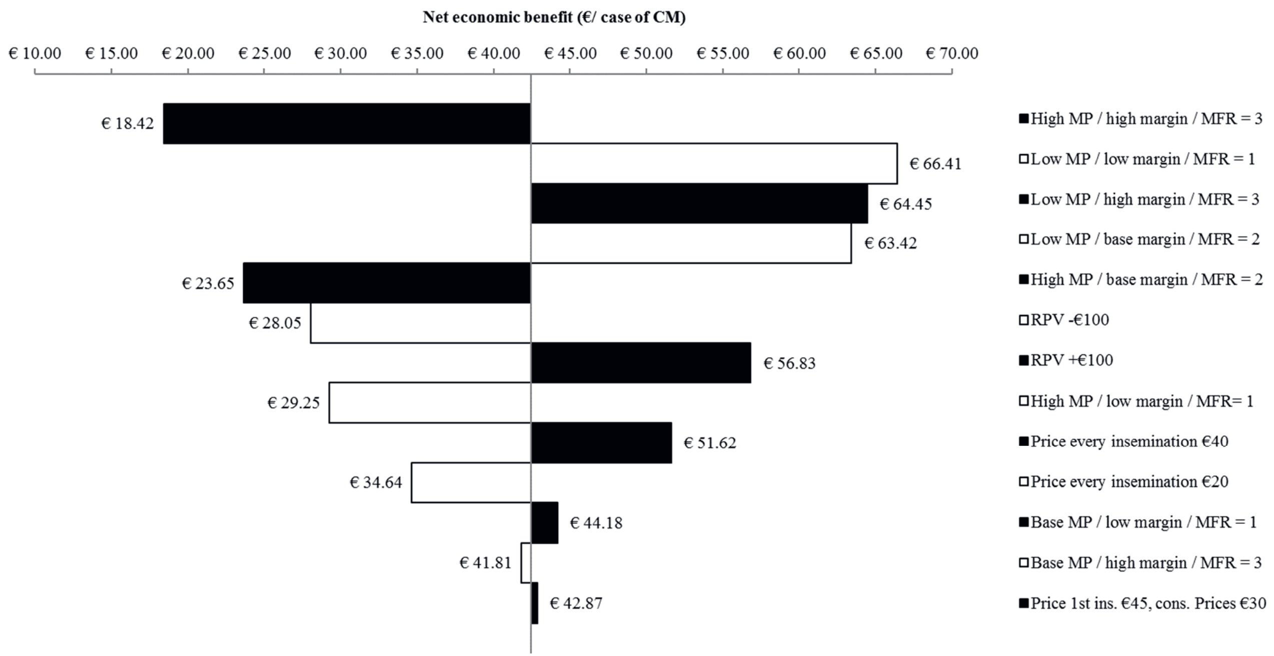

Figure 3. Tornado graph of the net economic benefit of meloxicam treatment versus no meloxicam treatment (€ / case of CM) when the value of the single economic parameters (Milk price (MP), margin, Milk and Feed price ratio (MFR) which is the ratio between milk price (€ per kg milk) and feed price (€ per kVEM) in which a high milk price (MP) is set at €0.47 per kg milk, medium MP is set at €0.32 per kg milk and low MP is set at €0.15 per kg milk, retention pay off value (RPV) and insemination costs) were changed in both scenarios

obtained in the sensitivity analysis. A scenario with a low milk price favors the meloxicam treatment scenario more than in the base scenario, with a net economic benefit of €66 with an MFR of 3, €64 with an MFR of 2 and €63 with a MFR 1.

5. DISCUSSION

In this study the standard treatment of mild to moderate CM in the first 120 days in milk was modelled with or without the additional benefit of meloxicam. Differences between treatments were based upon information derived from literature. Additional treatment with meloxicam of mild to moderate CM was found to increase CR from 0.21 to 0.31 and improve bacteriological cure rate (McDougall et al., 2016). In our study only the change in CR was taken into account. McDougall found no effects of an improved bacteriological cure rate on the dairy cows' performance, hence any further assumptions, such as the effect on milk production losses after meloxicam treatment, would have been speculative. It was therefore decided to model conservatively and, therefore, to solely simulate the positive effect of meloxicam on CR in cases of mild to moderate CM in the first 120 days in milk. Any additional positive effects of meloxicam treatment on bacteriological cure rate, improvements in subsequent SCC levels or reduced milk production losses would only further favor the economic outcome towards the meloxicam treatment scenario.

The difference in CR between treatment scenarios resulted in two main reductions, the proportion of cows culled for fertility reasons and the calving interval, both in favor of the meloxicam treatment scenario. Of those two effects, culling was found to have the highest economic impact on the net economic benefit, increasing the net cash flow with, on average, €79 per CM case per year in the non-meloxicam treatment scenario compared to the meloxicam treatment scenario. Culling percentages were 12% in the meloxicam treatment scenario and 25% in the non-meloxicam treatment scenario. Such culling rates may seem substantial and suggest a profound impact on the overall herd's replacement rate. It should, however, be considered that this concerns only cows with CM in the first 120 days in milk. This may, on an average 100 cow dairy farm, result in an average advantageous decrease of 1-2 removed animals for fertility reasons per year (Zwald et al., 2004; Lam et al., 2013). We modelled culling only due to fertility reasons and culling rules were strictly the same for each and every cow. In practice, culling rules are also applied, albeit often in a less strict form where farmers for example may allow an extra insemination for a high yielding dairy cow and vice versa. Nevertheless, relaxing the culling rules, either increasing or reducing the amount of allowed inseminations did not reveal any major changes to the net economic benefit (€44 versus €41 per case of CM per year, respectively). Although not a simulation target in this study, it should be recognized that in a previous study performed in New Zealand, with similar treatment scenarios compared to our study, very similar differences in culling rate were observed: 16% in the meloxicam scenario and 28% in the non-meloxicam scenario (McDougall et al., 2009).

The CI in the pregnant group was on average 405 days in the meloxicam treatment scenario and 416 in the non-meloxicam treatment scenario. Perhaps counterintuitively, the returns on milk production were found to be higher in the non-meloxicam treatment scenario, €2,562 per CM case per year, than the meloxicam treatment scenario, €2,520 per CM case per year. This is because the non-meloxicam scenario had a higher proportion of non-pregnant cows, 25% vs. 12%, which in both treatment scenarios showed higher returns on milk over pregnant cows. The higher returns on milk production for non-pregnant cows can be explained as these cows remain in production until culled, on average 382 days for both treatment scenarios, whereas the CI of the pregnant cows includes a 6 - 8 week dry-period. Nevertheless, an economic trade-off exists between culling and milk production. Our study showed that the benefits of higher returns on milk production, favoring the non-meloxicam treatment scenario are, however, cancelled out by the associated increased culling costs.

The costs associated with CM have been estimated in previous studies, however this study is the first to explore the costs of CM in relation to an improved CR. Therefore, and given the specific scenario simulated in this study, a direct comparison with other economic studies is not possible. Costs of mastitis are traditionally compared to healthy individuals, which was not an aim of our study. In this study we were interested in the economic difference between two treatment scenarios, which required a standardization of the results to € per case of CM per year to make results comparable. The found variation in net cash flow between treatment scenarios is substantial and to economically benefit most from the meloxicam treatment it is imperative that farmers treat all cases of mild to moderate CM with both antimicrobial therapy and meloxicam. The additional costs of meloxicam treatment were on average € 15, which means a mean return on investment of 2.8. Considering the overall cash flow on a dairy farm, the average net economic benefit of €42 per CM case per year favoring the meloxicam treatment scenario, is relatively small. Therefore, economic argumentation may not persuade all farmers to change current CM treatment practice. Farmers value animal health and welfare next to economic losses and job satisfaction as important components to change their mastitis management (Valeeva et al., 2007). Also, social norms and recognition for good stockmanship are drivers for the choice of treatment (Swinkels et al., 2015). Cows with CM are in pain (Fogsgaard et al., 2015) and treatment with meloxicam reduces pain (Fitzpatrick et al., 2013). In the case of lameness, it was found that a main motivator for farmers was pride in a healthy herd to reduce lameness incidence (Leach et al., 2010). Economic argument alone is unlikely to be effective in changing treatment behavior. Nevertheless, economic argumentation combined with the additional effects on a healthier herd status and welfare perspectives may lead to behavioral change. The addition of meloxicam to standard antibiotic mastitis therapy should, therefore, mainly be seen as an animal welfare promoting measure with economic beneficial effects.

6. CONCLUSION

This study has demonstrated that improvements in conception rate achieved by use of meloxicam, as additional therapy of mild to moderate CM in the first 120 days in milk, also have positive economic benefits. This inference remained true over a wide range of technical and economic inputs, demonstrating that use of meloxicam is likely to be cost-effective across many production systems.

7. ACKNOWLEDGEMENTS

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5

Chapter 5

European organic dairy farmers' preference for animal health management within the farm management system

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1. ABSTRACT

The expertise and knowledge of veterinary advisors on improving animal health management is key towards a better herd health status. However, veterinary advisors are not always aware of the goals and priorities of dairy farmers. To dairy farmers animal health is only one aspect of farm management and resources may be allocated to other more preferred areas. Veterinary advisors may experience this as non-compliant with their advice. To explore the preferences of EU organic dairy farmers for improved animal health management relative to other farm management areas an adaptive conjoint analysis was performed. A total of 215 farmers participated originating from organic dairy farms in France (n=70), Germany (n=60), Spain (n=28) and Sweden (n=57). The management areas udder health and claw health represented animal health management whereas barn, calf and pasture management represented potential conflicting management areas. Results indicate that EU organic dairy farmers differ in their preferences for improved animal health management within the farming system. In general, improved calf management was the most preferred area and improved claw health management was found to be least preferred, the remaining areas were of intermediate interest. Cluster analyses on claw health measures and udder health measures resulted in respectively seven and nine distinct preference profiles. The results indicate a high degree of variation in farmers' preference, which cannot be explained by the typical herd characteristics. With the individual preferences revealed by ACA, a veterinary advisor can now find out whether his intended advice is directed at a favourable or unfavourable management area of the farmer. If the latter is the case the veterinarian should first create awareness of the problem to the farmer. Insights in individual farmers preferences will allow veterinary advisors to better understand why farmers were incompliant with their advice and improve their advice by showing e.g. the potential benefits of their advice.

2. INTRODUCTION

Veterinary advisors play an eminent role in dairy farm management. Based on their expertise and knowledge on animal health, they try to identify the risk factors at the farm level and advise farmers accordingly. In practice, the adoption and implementation of the advice by farmers is often constrained. Although the rationale of the decisions of the farmer might be very logical, their decisions might be experienced by veterinary advisors as incompliant, potentially resulting in the opinion that farmers are hard-to-reach (Jansen et al., 2010). Although it is known that a successful advice requires awareness of the goals and priorities of the individual farmer and that tailoring advice will motivate farmers to implement management advice (da Silva et al., 2006), veterinary advisors often fail to do so (Derks et al., 2013).

Resource demands (e.g., labour, investments) in one field of farm management may provoke conflicts with management measures in other fields, and farmers allocate resources to those management areas which are preferred most, given their specific farming situation. A reason for the incompliance of farmers could be that veterinary advisors typically relate their advice to the field of animal health and make a trade-off decision between different animal health issues (e.g., lameness, mastitis), directing their advice to the most important issue. Improvement of animal health via better management is only one aspect of farm management. Better insights in the personal preferences of dairy farmers towards improved animal health management areas in relation to other farm management areas will lead to a better understanding by veterinary advisors of the motives and reasons for incompliance of a dairy farmer with the suggested advice.

While animal health is an important theme throughout the dairy chain, management of animal health might be more important in the organic dairy sector than in the conventional sector. Organic dairy farmers face an animal health status which is on average not better than the conventional sector (Hovi et al., 2003). Consumers generally expect a higher animal health status on organic farms (Hughner et al., 2007). However, general health status on organic dairy farms is not higher than on conventional dairy farms, meaning that it does not meet consumers' expectations. Health improvements are therefore crucial to comply with consumer expectations on organic farming. The pre-dominant animal health problems in organic dairy farming are mastitis and lameness (Rosati and Aumaitre 2004; Sutherland et al., 2013) and their incidences should be reduced both from a societal and economic perspective (Huijps et al., 2008; Bruijnis et al., 2010).

The targeted aim of this research was two-fold; the first aim was to investigate how improved animal health management is preferred by European organic dairy farmers in relation to other areas of farm management, using an Adaptive Conjoint Analysis. The second aim was to specifically investigate if farmers could be clustered based on their preference for animal health management measures and to what extent clustering can be explained by general herd characteristics.

3. MATERIAL AND METHODS

RESEARCH SET-UP AND APPLICATION

Within this study, elicitation of farmers' relative preference towards different management areas was studied using the computer based Adaptive Conjoint Analysis method (ACA; Sawtooth Software Inc., 2014). Although primarily known as a marketing tool, the ACA method has been successfully applied in the field of agriculture and specifically dairy farming to evaluate preferences among management options (Valeeva et al., 2007; Huijps et al., 2009; Boersema et al., 2013).

ACA is a method to determine preferable characteristics of a defined product, in which respondents make a series of trade-offs among the product characteristics. Analysis of these trade-off decisions will reveal the relative preference of the studied characteristics. In ACA a product is assumed to comprise characteristics (named attributes), each with its own levels (e.g., colour is an attribute with red, white and blue as levels). ACA consists of four distinct sections in which information is derived from the respondent on his or her preferences for the different levels. After (and during) each section the derived information is updated and used as input for the next step. The derived information is presented by the part-worth utilities, and these are always zero-centered. Part-worth utilities comprise information on the relative preference for the attributes, but more importantly contain vector information on which level is preferred over another. The final results are estimated with Hierarchical Bayes estimation and result in the final part-worth utilities which are estimated for each of the respective levels of the attribute. The difference between the most and least preferred level within an attribute will result in the relative preference scores for each attribute.

Following ACA terminology in this study, the farmer is the respondent, and the product is defined as farm management, with farm management areas as attributes and respective management measures as levels (Table 1). Management areas and their respective measures were derived from a literature search and experts' opinions. Improved udder health management and improved claw health management were both selected as representatives for animal health management. The remaining management areas (barn, calf and pasture management) were chosen because of their diversity and their potential as areas of improvement of farm management. To explore and detect (dis)similarities among farmers' management preferences, the constructed management measures (three levels per attribute) were defined as precise as possible, not mutually exclusive and easy to be implemented. Moreover, to control for any imbalance in labour requirements between management measures farmers were asked to assume labour would not be restrictive in their decision to adopt a certain management measure. A more in-depth description of ACA estimation and construction can be found in a technical paper of Sawtooth Software (2007).

Table 1 Description of attributes (management areas) and levels (management measures) used in the Adaptive Conjoint Analysis to elicit farmers' preferences

Attribute	Short description	Full description of management measures
Barn management	Sufficient feed	Ensure sufficient feed is accessible for all lactating dairy cows for at least 12 hours per day
	Clean water troughs	Clean all drink water troughs daily
	Clean calving pen	Clean and disinfect calving pen after each calving
Calf management	Colostrum supply	Supply colostrum to the calf within four hours after birth
	Disinfect calf pens	Thoroughly disinfect calf pens when calves leave the pen
	Measure chest girth	Measure chest girth of all calves (age groups 0-1 yr) bimonthly to monitor development and growth
Claw management	Trim hoofs	Trim hoofs of lame cows immediately after detection
	Check lame cows	Check treated lame cows 1 week after treatment again
	Place footbath	Place footbath once every two weeks
Pasture management	Remove weed	Mechanically remove most weeds from all grassland twice per year
	Monitor grass growth	Measure grass growth once per week during growth season
	Rotational grazing	Move dairy cows to different paddock in order to apply rotational grazing

Udder management	Milker's gloves	Use of milker's gloves during milking
	Prestripping	Post treatment of teats of all cows after milking (dipping or spraying)
	Milk (sub)clinical last	Milk cows with a high somatic cell count or clinical mastitis last

SURVEY POPULATION

The survey population of 216 organic dairy farmers originated from four different European Union (EU) countries: France (n=71), Germany (n=60), Spain (n=28) and Sweden (n=57). This population was part of a EU 7th framework research project aimed to improve animal health on EU organic dairy herds (IMPRO: Impact matrix analysis and cost-benefit calculations to improve management practices regarding health status in organic dairy farming). Farmers from the respective countries were eligible for inclusion in the study when the following four requirements were satisfied: 1) Test-day milk records had to be available from January 2012 onwards, 2) Farms had to be officially labelled as organic for at least one year at the start of the questionnaire (February 2013), 3) Farms had to be expected to stay in operation at least for the immediate future and, 4) A representative country herd size was requested. Final stages of the selection process differed per country; French farms were selected by a local organic advisor and originated from three administrative regions (Morbihan, Loire-Atlantique, and Lorraine). German farms were selected by either organic dairy advisors or veterinary practices. Out of the willing participants a representative sample was drawn. German farms were located in north Germany (Schleswig-Holstein, Mecklenburg Vorpommern and Lower-Saxony), central Germany (Hesse and Northern Bavaria) and south Germany (Lower Bavaria and Baden Württemberg). All Spanish organic dairy farms were first contacted by phone by the researcher, all willing and eligible farmers were included in the study. Spanish farms were located in Galicia, Asturias, Cantabria Basque country and Catalonia. Swedish organic farms were located in north and west Sweden (Gävlesborg and Värmlands län), central east Sweden (Uppsala and Västmanlands län), central Sweden (Stockholms, Västra götäland and Östergötlands län) and south Sweden

(Västra götalands län) and were first sent an invitation letter after which eligible and willing farmers were included.

Within the EU the share of organic farming in dairy farming varies over the different member states. Sweden is one of the member states with the largest share (14%) of organic dairy cows out of the total number of dairy cows whereas Spain has a relatively small share of 1% (Eurostat, 2014). The average share of organic dairy cows in the EU is 3% which equals the share of Germany and France. In absolute values, share and degree of settlement of organic development these four countries capture the variation of organic dairy production within Europe.

DATA COLLECTION AND TRANSLATION PROCESS

The draft version of the ACA was discussed with the country specific researchers and tested on a Dutch dairy farmer with experience in organic dairy farming. Potential conflicting measures or ambiguities were omitted or changed. The final version of the ACA was then translated to the country specific language via multiple translation sessions, together with the research team of each country. The translated documents were re-translated in English, as a final validity check. The re-translated documents were compared with the original. When there were differences, the translated ACA was then adjusted to ensure the ACA was interpreted the same by farmers from different countries. Prior to the farm visits, local researchers were instructed on how to administer the ACA. During the data collection and prior to the ACA, socio-economic characteristics (certification, education and agricultural area) were collected via a paper questionnaire. Technical herd characteristics (farm size, milk yield, and somatic cell count) were collected via herd recordings, while the percentage of lame cows was assessed during the farm visits following the Welfare Quality® protocol.

ADAPTIVE CONJOINT ANALYSIS SET-UP

The ACA consists of four distinct sections each dedicated to eliciting farmers' preference for different farm management areas by making trade-offs between sets of management measures. In the first section the preferences for each combination of management area (5 attributes) and related management measures (3 levels) were elicited, resulting in a total of 15 crude part-worth utility values.

In the second section, famers were asked to indicate how strong their preference between the most and least preferred management level was under ceteris paribus conditions. Based on this information the crude part-worth values were updated to prior part-worth utility values. In the third section farmers made paired comparisons between multiple levels of different attributes. Responses after each comparison were used to select the next paired comparison question by updating the estimates of the farmers' part-worth utilities The fourth and final section was a consistency check in which farmers were presented with three concepts of each three management measures and asked how preferable each of these concepts were for implementation in their daily farming routine. Data obtained from the final task was used to analyse correlations between the part-worth utilities and likelihood responses and resulted in the consistency coefficient.

ESTIMATING PART-WORTH UTILITIES

The part-worth utility values derived after the third step served as input for estimating the final part-worth utility values using Hierarchical Bayes estimation. The Hierarchical Bayes estimation follows an iterative process and assumes individual part-worths to have a multivariate normal distribution:

$$\beta_i \sim Normal(\alpha, D)$$

In which β_i is a vector of part-worths for the i-th individual, α is a vector of means of the distribution of individuals' part-worths and D is a matrix of variances and covariances of the distribution of part-worths across individuals.

Given an individual's part-worth utility values, the probabilities of responding in a particular way are governed by a multivariate normal distribution, which is described as follows:

$$y_{ih} = x_{ih}'\beta_i + e_{ih}$$

in which y_{ih} is the answer to question i by respondent h, x_{ih}' is a row vector of values describing the i-th question for respondent h and e_{ih} is an independent identically distributed error term, distributed normally with mean of zero and variance σ^2. The estimated parameters are the vectors of β^i, the vector α, the matrix D and the scalar σ. A more in-depth description of Hierarchical Bayes estimation can be found in a technical paper of Sawtooth Software (2006).

PREFERENCE SCORE

The difference between the highest and lowest final part-worth utility represents a relative measure of preference, named preference score, for the respective management area. A higher preference score represents a higher preference for a certain management area relative to the other management areas. To account for farmers which gave consistently more extreme answers, the utilities were made comparable between farmers. The sum of the preference scores of each farmer was therefore set to equal 100. A preference score of 20 for each of the five management areas would thus represent no particular preference for any of the five management areas (all are equally important).

CLUSTER ANALYSIS

To reveal farmers profiles for different attributes related to animal health, a cluster analysis was performed separately on the part-worth utilities of improved udder-health management and improved claw-health management using SAS/STAT® software (SAS Institute Inc., Cary, NC). Since cluster procedures performs poorly with elliptical data, part-worth utilities were transformed (PROC ACECLUS) into a spherical form by computing canonical variables. The proportion of pairs used for estimating canonical variables was set at 0.03. The farmers were clustered based on the transformed part-worth utilities. The cluster method used was the Ward minimum-variance method which in the first stage considers each of the farmers as a single cluster. Ward's method has a good performance for recovering the original clusters (Mingoti and Lima, 2006). At each consecutive stage, the farmers were compared with each other by using a measure of distance.

The distance between Cluster CK and CL is defined as:

$$D_{KL} = \frac{\| \overline{X}_K - \overline{X}_L \|^2}{\frac{1}{N_K} + \frac{1}{N_L}}$$

In which C_K and C_L have vectors with means X_K and X_L and sizes N_K and N_L, respectively. The distance D_{KL} between C_K and C_L is a function of the squared Euclidian distance between the cluster centroids. The two clusters with the smallest distance (or larger similarity) are joined. The procedure is repeated until the desirable number of clusters is achieved. At each cluster stage the Pseudo F and Pseudo T^2 are reported. Higher values indicate the presence of possible clusters and need further investigation. A visual assessment of the corresponding tree-diagram in relation to the R^2 was then used to determine the final number of clusters.

4. RESULTS

RESPONSE

On average farmers completed the questionnaire within 21 (SD ± 9) minutes. The average consistency coefficients were 52% (SD ± 18.2%). Feedback on the ACA from the farmers indicated that the third task, the paired comparisons, was sometimes hard to assess. The average time used to complete the ACA and the consistency coefficient gave no reason to exclude farmers.

HERD CHARACTERISTICS

A total of 71 French, 60 German, 28 Spanish and 57 Swedish organic farmers participated. One French farm was omitted as it was not able to comply with the inclusion criteria. The average number of years a farm was certified as organic equalled 9.2 years. Between countries the average period of certification varied from minimal 6.8 years in Spain to maximal 10.1 years in Germany. The average agricultural area was 158 ha. per farm with the largest area per farm in Sweden (276 ha.) and the lowest area per farm in Spain (70 ha.). The variation in agricultural area per farm between countries corresponds with the variation in herd size; herd size in Sweden was on average the largest (101 dairy cows) and in Spain the lowest (59 dairy cows). The average derived income by farmers from dairy related activities varied between the four countries from 72.5% in Sweden to 82.0% in Germany. Swedish organic dairy cows produced relatively more than (9,000 kg milk/cow versus 6,036 kg milk/cow) French dairy cows.

PREFERENCE SCORES

Average preference scores and utility values for the management areas and measures are presented in Table 2. Calf management had on average the highest preference score (24.9) compared to all other attributes. Within calf management the measure "colostrum supply" was most preferred and the measure "chest girth" was least preferred. Farmers had a utility value close to zero for the measure "disinfect calving pens" suggesting no specific preference for this measure. Within barn management the provision of

Table 2 The preference scores for the different management areas (min-max) and final part-worth utility scores (5%-95%) for the related management levels. Higher values indicate a higher preference for the respective management area or measure.

Attribute	**Preference score**	**Part-worth**	**5%**	**95%**
Level	**(min - max)**	**utility (St. dev.)**	**percentile**	**percentile**
Barn	19.61 (0.55 – 35.63)			
Sufficient feed		9.18 (5.60)	-1.46	17.11
Clean water troughs		-5.72 (5.80)	-14.44	3.81
Clean calving pen		-3.45 (6.32)	-13.76	7.82
Calf	24.90 (3.39 – 43.36)			
Colostrum supply		11.51 (5.23)	1.54	18.88
Disinfect calf pens		0.26 (5.28)	-9.44	9.14
Measure chest girth		-11.76 (5.45)	-18.94	-1.08
Claw	17.26 (1.70 – 35.02)			
Trim hoofs		7.23 (4.94)	-1.42	14.69
Check lame cows		0.19 (4.68)	-9.32	7.87
Place footbath		-7.43 (5.42)	-14.94	2.82
Pasture	18.08 (1.47 – 38.72)			
Remove weed		-0.79 (6.93)	-12.81	10.57
Monitor grass growth		-5.65 (6.12)	-14.50	6.09
Rotational grazing		6.45 (6.52)	-4.60	15.94
Udder	20.16 (3.42 – 51.11)			

Milker's gloves	-5.89 (7.62)	-17.74	7.76
Prestripping	2.23 (8.31)	-10.67	15.54
Milk (sub)clinical last	3.66 (8.83)	-10.98	17.73

sufficient feed for at least 12 hours per day was the most preferred management measure. Both "clean calving pen" and "clean water troughs" had a negative utility value suggesting a low preference. Within pasture management the measures "rotational grazing" was the most preferred management measure whereas "monitor grass growth" was the least preferred management measure. Farmers had a slightly negative utility for the measure "remove weed".

Udder health management was on average more preferred than claw health management. Within udder health management both "prestripping" and "milk (sub)clinical last" were given a positive utility value in which the latter measure was more preferred. "Use of milker's gloves" was least preferred. Within claw health management "trim hoofs" was preferred most and "place footbath" was least preferred. Variation among part-worth utility values was large and preferences for the most and least preferred measures varied substantially between farmers.

CLUSTER ANALYSIS

The cluster analysis was performed on the utility values of udder health management and claw health management to obtain insights in farmers' preferences with respect to animal health management measures. The cluster analyses on the part-worth utility values of claw health and udder health management revealed, respectively, 7 (C1 – C7) and 9 (U1 – U9) distinct clusters (Tables 3 and 4). The R-square of the claw health cluster analysis was equal to 0.853 and of the udder health cluster analysis to 0.785. Generally, there was a large variation in preference scores and part-worth utility values between clusters.

Cluster C1, C3, C5 and C6 had an average preference score ≥20 (24, 20, 22 and 22), while clusters C2, C4 and C7 had an average preference score <20 (12, 11 and 9). General herd characteristics nor country significantly influenced the cluster outcome. Clusters C3 and C7 gave a higher part-worth utility value to the measure "place footbath" than to the other claw clusters. On average C3 and C7 had a larger herd size (94 and 65 dairy cows) and agricultural area (279 and 210 ha) than other herds. Cluster C3 was found to be least experienced in organic farming with 5 years of organic experience. Cluster C7 had a high production per cow (9101 kg milk/ cow/ year) compared to the overall herd average (7747 kg milk/ cow / year). Clusters C1, C5 and C6 were least productive with a production of 7375, 7146 and 7128 kg milk/ cow / year, respectively. The on-farm assessment of claw health following the welfare quality protocol indicated that on average 14% of all cows was moderately lame and 4% severely lame. Cluster C3 had on average the highest point prevalence of dairy cows both moderately and severely lame (18 and 6%), while cluster C7 had the lowest point prevalence of lame dairy cows (9 and 2%). C1 and C5 had on average a higher point prevalence of moderately lame animals compared to the herd average (both 16%), while C2 and C7 had a lower point prevalence of severely lame animals (both 2%). Clusters C4 and C7 indicated claw health as more relevant on their farm compared to the other clusters.

Clusters U4, U5, U6, U7 and U9 had an average preference score ≥20 (26, 24, 23, 28 and 24) and clusters U1, U2, U3 and U8 had an average preference score <20 (17, 11, 13 and 13). Within the 9 clusters preference for the three management measures varied greatly. However, in most clusters (U2, U3, U4, U5 and U7) the measure "milker's gloves" was least preferred. Clusters U4, U5 and U6 were certified as organic the shortest (8, 7 and 7 years) whereas all other clusters were certified for a duration above average (varying from 9 to 12 years). The average number of years of education varied between 10 to 13 years between clusters. Cluster U2 had on average the largest agricultural area (233.6 ha) and cluster U8 had the smallest (94 ha). Average milk production was highest in cluster U4 (8176 kg milk/ cow/ year), although all clusters represented a production close to the overall herd average of 7748 kg milk/ cow/ year. All clusters with a preference score ≥ 20 had a higher prevalence of dairy cows above a SCC threshold of 300.000 cells/ml than clusters with a preference <20. Clusters U2, U5 and U6 indicated udder health as more relevant on their farm compared to the other clusters.

5. DISCUSSION

RESPONSE

Too complex attributes and levels or a poor constructed ACA will result in negative consistency coefficients (indication of inconsistent answers) and/or respondents rushing (or taking too much time) through the questionnaire. In our study the average consistency coefficient is lower compared to previous comparable ACA studies (Valeeva et al., 2007: 75.7% - 88.8%; Boersema et al., 2013: 67% ± 19.4). Feedback from the farmers indicated that the third task, the paired comparison, was sometimes experienced as difficult to assess. This might explain why the consistency coefficient is lower compared to comparable ACA studies. However, consistency coefficients and the time used to complete the ACA gave no reason to exclude farmers. We concluded that although some farmers found the paired comparison task hard, they understood the overall concept. Therefore, the results are valid. Furthermore, the part-worth utilities indicate a large variation in preference between farmers for the different management measures, which indicates farmers were able take the assumption on time availability into account (otherwise management measures would be ranked similar between farmers with the least laborious measure preferred most).

Table 3 Description of mean herd characteristic, health issues and ACA results of part-worth utilities and preference score per claw health cluster (C1 - C7) and for all farms (n=215). Standard deviation is put between brackets

	C1	C2	C3	C4	C5	C6	C7	ALL
Farmers (n)	40	50	16	28	45	14	22	215
Dairy cows (n)	56 (23)	56 (49)	94 (78)	54 (35)	50 (30)	47 (24)	65 (47)	58 (43)
Milk yield (kg milk/ cow / year)	7375 (1578)	8055 (2113)	7710 (1899)	7821 (2005)	7146 (1401)	7128 (2188)	9100 (2312)	7748 (1963)
Agricultural area (ha)	115 (62)	167 (184)	279 (346)	151 (134)	149 (232)	110 (64)	210 (145)	160 (186)
Organic certification (years)	8 (7)	10 (8)	5 (6)	10 (7)	10 (7)	9 (5)	9 (6)	9 (7)
Moderately lame cows (%)	16 (11)	13 (11)	18 (11)	13 (11)	16 (10)	12 (10)	9 (11)	14 (11)
Severely lame cows (%)	5 (6)	2 (4)	6 (12)	4 (8)	4 (5)	4 (6)	2 (6)	3.5 (6)
Relevance claw health[1]	2.1 (1.4)	2.2 (1.2)	2.4 (1.0)	1.7 (1.3)	2.2 (1.3)	2.4 (1.0)	1.7 (0.9)	2 (1)
Part-worth utility 'trim hoofs'	11 (3)	6 (2)	10 (3)	2 (2)	12 (2)	3 (4)	0 (4)	7 (5)
Part worth utility 'check lame cows'	3 (2)	0 (2)	-10 (1)	4 (1)	-1 (2)	9 (2)	-3 (4)	0. (5)
Part-worth utility 'place footbath'	-13 (2)	-6 (2)	-1 (3)	-6 (2)	-10 (1)	-12 (3)	3 (4)	-7 (5)
Preference score	24 (5)	12 (3)	20 (4)	11 (2)	22 (3)	22 (3)	9 (6)	17 (7)

[1] Farmers were asked to rank the following production diseases: fertility problems, udder diseases, claw and limb diseases, metabolic disorders and other in which 1 was most relevant and 5 was least relevant

Table 4 Description of mean herd characteristic, health issues and ACA results of part-worth utilities and preference score per udder health cluster (U1 – U9) and for all farms (n=215). Standard deviation is put between brackets

	U1	U2	U3	U4	U5	U6	U7	U8	U9	ALL
Farmers (n)	27	20	35	23	31	32	25	12	10	215
Dairy cows (n)	60 (35)	63 (44)	74 (57)	47 (29)	44 (27)	64 (68)	57 (26)	46 (13)	63 (22)	58 (43)
Milk yield (kg milk/ cow / year)	7616 (1465)	7922 (2291)	7766 (1741)	8176 (2142)	7274 (2266)	7740 (2079)	8008 (2212)	7871 (1327)	7465 (1869)	7748 (1963)
Agricultural area (ha)	135 (118)	234 (299)	178 (127)	136 (97)	143 (277)	177 (219	164 (130)	94 (56)	143 (88)	160 (186)
Organic certification (years)	9 (7)	11 (6)	10 (7)	8 (6)	7 (6)	7 (5)	10 (10)	12 (8)	12 (9)	9 (7)
Relevance udder health[1]	1.6 (1.0)	1.2 (0.9)	1.9 (1.0)	1.8 (1.1)	1.3 (0.8)	1.2 (0.7)	1.6 (1.0)	1.8 (1.1)	1.6 (0.8)	1.5 (0.9)
Cows above SCC threshold (%)[2]	17 (7)	20 (8)	19 (6)	23 (10)	22 (13)	23 (12)	21 (7)	18 (5)	22 (6)	21 (9)
Part-worth utility 'milker's gloves'	6 (3)	-6 (2)	-5 (4)	-16 (3)	-11 (4)	-4 (3)	-14 (2)	5 (4)	-4 (3)	-6 (8)
Part worth utility 'prestripping'	3 (4)	0 (2)	7 (2)	7 (3)	-3 (2)	-9 (3)	14 (3)	-8 (5)	14 (2)	2 (8)
Part-worth utility 'milk (sub)clinical last'	-9 (4)	5 (2)	-1 (3)	9 (2)	14 (4)	13 (4)	-1 (3)	2 (2)	-10 (2)	4 (9)
Preference score	17 (5)	11 (3)	13 (4)	26 (5)	24 (8)	23 (7)	28 (5)	13 (8)	24 (3)	20 (8)

[1] Farmers were asked to rank the following production diseases: fertility problems, udder diseases, claw and limb diseases, metabolic disorders and other in which 1 was most relevant and 5 was least relevant

[2] Threshold was set at 300.000 cells/ml

PREFERENCE SCORES

Given the results, udder health management is more preferred than claw health management, which might suggest that udder health is experienced as more of a problem than claw health in organic dairy systems. In general, culling is one of the main contributors to the costs of mastitis and lameness on a dairy farm (Bruijnis et al., 2010; Hogeveen et al., 2011). In Swedish and French organic dairy herds it was found that the main reason for culling dairy cows was primarily related to udder health problems and less to leg problems (Seegers et al., 1998; Ahlman et al., 2011). Perception of the farmer on the impact of the problem also influences the preferences as losses due to mastitis are more visible as they imply direct effects (discarded milk, treatment costs) whereas losses due to lameness are more gradual (drop in milk yield) and therefore experienced as less of a problem by farmers (Bruijnis et al., 2013).

CLUSTER ANALYSIS

Increased herd size could affect farmers preference in favour of less labour-intensive measures. Generally, “place footbath” implies less labour compared to “check lame cows” or “trim hoofs” which might explain why “place footbath” is more preferred by clusters C3 and C7 in comparison to the other clusters. Next to herd size, C3 could comprise farmers relating their farm management to conventional system where the use of a footbath is more common practice (Stiglbauer et al., 2013), since they were more recently converted to organic farming. Animal health clusters were unlikely to be affected by agricultural area, which is correlated to herd size, since most organic feed is traditionally home-grown (Hovi et al., 2003).

The level of animal health problems is likely to affect preference score and part-worth utility. A review by Dufour et al (2011) found “prestripping” to be associated with low SCC herds to detect early cases of clinical mastitis. However, we did not find that “prestripping” was more preferred in clusters with a low SCC. In a study of Jansen et al. (2010) increased BMSCC was found to affect farmers' behaviour; our study suggests SCC could influence farmers' towards a higher preference score for udder health.

Most clusters with a higher-than-average prevalence of severely lame cows were found to have an average preference ≥20, although cluster C4 had a preference <20. Poor animal health status is correlated with a drop in milk production (Warnick et al., 2001; Halasa et al., 2007; Bicalho et al., 2008). A drop in milk production could be a more important indicator for claw health other than udder health and might influence the cluster outcome, which is supported by the lower milk production in clusters C1, C5, C6 compared to the relatively high milk production and good claw health status in clusters C2 and C7. Although not significantly indicated by the results from this study, some herd characteristics as milk production, prevalence of severely lame cows, and SCC could influence the outcome of part of the clusters, but not all.

It is likely that other aspects, which are not easily derived from herd recordings or veterinary visits, play an important role in farmers preference, which was also suggested by Huijps et al. (2009). Farmers' decisions are influenced by multiple factors related to personal characteristics (age, education, etc.) (Vanslembrouck et al., 2002), structure of the farm (farm type, farm size, technical performance, etc.) (Potter and Gasson, 1988; Edwards-Jones, 2006), social background (information flow, local culture, attitude of friends, etc.) (Solano et al., 2003) and job satisfaction (procrastination of boring or nasty jobs). It would be interesting to investigate how socio-economic characteristics and social capital (e.g. social norms, obligations and expectations) would affect farmers' preferences on management areas by using a similar approach as for example Burton et al. (1999) and Mathijs (2003). Knowledge on the key factors affecting farmers' preference will aid veterinary advisors towards a better understanding of why farmers might remain incompliant with their advice.

IMPLICATIONS VETERINARY ADVICE

Our aim was to explore farmers' preferences towards animal health and not to evaluate specific veterinary advice. The constructed measures were used as examples of potential improvements to the specific management area. In real life many different management measures could be advised by a veterinary advisor (Dufour et al., 2011) which would be impossible to fit in an ACA. To correct for the imbalance in labour requirements among management measures, farmers were asked to assume they would experience no labour restrictions in implementing the measure. This assumption influences the results when considering the actual adaptation of measures in practice. For these reasons the outcome of our study cannot be seen as a potential set of measures suitable for a veterinary advice. Results of our study show a large variation in preferences between farmers and confirms our belief that veterinary advisors cannot presume a certain preference based on herd characteristics alone.

The expertise and advice from veterinary advisors remain indispensable to the farmers. However, Derks et al. (2013) showed that veterinarians were not always aware of the goals of farmers regarding herd health management. Our findings suggest that veterinary advisors should become aware of the farmers preferences towards different animal health management in relation to other areas of farm management. A more thorough understanding of the trade-off decisions of an individual dairy farmer will lead to a better mutual understanding of the veterinary advisor and farmer. When veterinary advisors are aware that their advice is directed at an unfavourable management area they need to strengthen their advice further by discussing with the farmer why the disease is a problem to the farmer and/or by showing the benefits of their advice (e.g. health benefits or economic benefits). ACA methodology can be a good method to explore which management measures are (un)favourable by farmers.

In conclusion this study shows that EU organic dairy farmers differ in their preferences for improved animal health management within the farming system. In general, improved claw health management is the least preferred management area, while improved udder health management is of intermediate preference. Generally, it is expected that advise directed at claw health will have a larger number of farmers incompliant with the advice relative to udder health management advice. The results indicate a high degree of variation in farmers' preference, which cannot be explained by the typical herd characteristics. With the individual preferences revealed by ACA, a veterinary advisor can now find out whether his intended advice is directed at a favourable or unfavourable management area of the farmer. If the latter is the case the veterinarian should first create awareness of the problem to the farmer. Which measures are then best implemented on the farm remains a task of the veterinary advisor and cannot be based on the ACA results. Insights in individual farmers preferences will allow veterinary advisors to better understand why farmers were incompliant with their advice and improve their advice by showing e.g., the potential benefits of their advice.

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6

Chapter 6

General discussion

1. INTRODUCTION

The aim of this dissertation was to gain farm specific insights in how dairy cattle production disorders can be managed from an economic perspective to support farmers' decision making. I studied the economic impact of four of the most important production disorders: mastitis, ketosis, lameness and metritis As described at length in chapter 1 these production disorders are common on dairy farms, and to date each of the production disorders has a high incidence at the farm level (Table 1). The economic impact for each of these production disorders is substantial as has been studied in chapter 2 and 3. To outline, the costs associated with the occurrence of production disorders are known as failure costs, i.e. the animal fails to reach its full potential (Hogeveen et al., 2011). Resources used to prevent production disorders from occurring are the prevention costs. The total production disorder costs should be the sum of both failure and preventive costs. Unfortunately, almost always only failure costs are reported, with some exception for mastitis research (e.g. Yalcin et al., 1999; Huijps et al., 2008; Aghamohammadi et al., 2018). The consequence is that there is a one-sided view on the total costs of production disorders and an underestimation of the total costs of production disorders.To support decision making at the farm level there needs to be a focus on both failure and preventive costs to reflect to actual total costs of production disorders.

Most failure costs calculations in scientific literature have focused on estimating the generic case of a production disorder using generic assumptions either on technical data (such as milk production levels) and/or price input (Table 2). As a consequence their results refer to the average or typical farms within a production system (e.g. Mahnani et al., 2015; Liang et al., 2017; Mostert et al., 2017). Such studies do not support the individual on-farm decision making as they fail to reflect the actual conditions under which the farm operates. To strengthen the decision support regarding animal health we need to use tools which allow for empiric input, both technical and price input, to estimate farm specific failure costs. There is a lack of on-farm specificity of the total cost estimates, and thus a failure to reflect individual farming conditions. Furthermore, it is not possible to make direct comparisons between different cost estimates for different production disorders as some studies attribute cost to other disorders leading to potential double counting. Which overestimates the impact of total on farm failure costs when comparing these studies (e.g., McArt et al., 2015; Mostert et al., 2017). In the following sections I will discuss how this dissertation contributed to support on-farm decision making. Thereafter I will propose which fields/ theories should be studied to further strengthen the on-farm decision making.

2. SYNTHESIS OF THE RESULTS

As indicated before, costs of production disorders consist of indirect and direct costs. For farmers, the directs costs are relatively clear (e.g., expenditures on treatments, labour requirements for treatment) while the indirect costs, such as those resulting from an earlier herd removal, may go unnoticed. In order to generate accurate on-farm failure costs estimations a structured framework is needed to account for both types of costs. Such a framework structuring the cost components related to the production disorders mastitis, lameness, ketosis and metritis is presented in Chapter 2. The economic basis for this framework is the cost-benefit analysis method (Huime et al., 1997). Although not the most novel approach, it was the most appropriate method to apply, as it includes all relevant cost components in a structured and transparent manner, while allowing for an integration with epidemiological data on production disorder impacts. I used empiric data, both on technical and price input, to evaluate the economic impact of multiple production disorders and used the same approach for each production disorder. Structuring of four different production disorders into one framework allowed for a direct on-farm comparison between the different production disorders as well as comparisons between farms and countries, which is particularly novel and not performed in other studies. In most scientific studies, with only a few exceptions (McArt et al., 2015;

Production disorder	Incidence	Units	Reference
Mastitis	4.8	cases per 100 cows	Alanis et al. (2022)
	4.2 -5.6	% (between 14 - 100 days in milk)	Zigo et al. (2022)
	15.2	%	Ruprechter et al. (2018)
	10.6	%	Ribeiro et al. (2016)
	6.45 - 8.87	%	Doerfler et al. (2018)
	27.6	%	Cruz et al. (2021)
Ketosis	35	% (BHBA[1] ≥1,2 mmol/L 3-17 Days in milk)	Daros et al. (2020)
	44	% (BHBA ≥1,2 mmol/L 3-16 Days in milk	McArt et al. (2012)
	41	% (NEFA[2], 1-7 days in milk)	Chapinal et al (2012)
	12	% (NEFA, 8-14 days in milk)	Chapinal et al (2012)
Lameness	18.9	%	Ranjbar et al. (2016)
	6.2	%	Ribeiro et al. (2016)
	25 - 48	% (depending on scoring frequency)	Eriksson et al. (2020)
	8.2	cases / 100 cows / wk (dry period only)	Daros et al. (2020)
	5	%	Cruz et al. (2021)

	8.1 - 12.4	Cases / 100 cows	Fabian et al. (2014)
Metritis	28	%	Daros et al. (2020)
	26.6	%	Ruprechter et al. (2018)
	18.1	%	Ribeiro et al. (2016)
	24.7	% (Mild metritis)	McCarthy and Overton (2018)
	3.5	% (Severe metritis)	McCarthy and Overton (2018)
	47.3	%	Martinez et al. (2012)
	4.4	% (Retained placenta metritis)	Cruz et al. (2021)

Table 1. Overview of recent scientific literature on incidence levels of the production disorders mastitis, ketosis, lameness and metritis

[1] Beta hydroxybutyrate

[2] Non-esterified fatty acids

Production disorder	Failure costs	Unit	Input	Model type
Mastitis				
Puerto et al. (2021a)	287 - 908	$(CAN) / case	Emperic farm data and generic price input	Deterministic model
Dahl et al. (2018)	149	$(USD) / case (D1 - D75 of gestation)	Emperic farm data and generic price input	Deterministic model
Aghamohammadi et al. (2018)	199	$(CAN) / cow year	Emperic farm data and price input	Deterministic model
	349	$(CAN) / cow year		
Ketosis				
Mostert et al. (2018)	130 (39-348)	€ / case	Generic farm data and price input	Biodynamic stochastic model
Steeneveld et al. (2020)	709 (64 - 1196)	€ / case of clinical ketosis	Generic farm data and price input	Biodynamic stochastic model
	150 (18 - 422)	€ / case of subclinical ketosis		
Raboisson et al. (2015)	257 (72 - 442)	€ / case of subclinical ketosis	Generic farm data and price input	Stochastic model
McArt et al. (2015)	256	$(USD) / case ketosis multiparous cow	Generic farm data and price input	Deterministic model
	375	$(USD) / case ketosis primiparous cow		

Lameness				
Charfeddine and Pérez-Cabal (2017)	53 - 232	$(USD) / case	Generic farm data and price input	Deterministic model
Puerto et al. (2021b)	507 - 1083	$(CAN) / case	Emperic farm data and generic price input	Deterministic model
Metritis				
Lima et al (2019)	267 - 410	$(USD) / case	Emperic farm data and generic price input	Deterministic model
Perez Baez (2021)	513 (240 – 884)	$(USD) / case	Emperic farm data and generic price input	Stochastic model
Mahnani et al 2015	162,3 (146 - 175,7)	$(USD) / case (5% - 95% Interval)	Emperic farm data and price input	Deterministic model

Table 2. Overview of recent failure cost estimates, input used and model type to estimate costs for the four production disorders mastitis, ketosis, lameness and metritis.

Raboisson et al., 2015; Liang et al., 2017), the failure costs of single disorders only has been studied (Bruijnis et al., 2010; Heikkilä et al., 2012; Gohary, 2016), and use of both empiric price and technical input is rare (Table 2). Results from Chapter 2 revealed a substantial difference in failure costs between production disorders, ranging from 0 to 462 €/cow per year as well as substantial differences between and within countries (included countries were Germany, Spain, France and Sweden). Average failure cost estimates were in line with earlier studies on the failure costs of these production disorders (Table 2), and, although in line with results of earlier simulation studies, it can now be confirmed that at a farm level such variation actually does exist. Hence, to support the decision-making process of an individual farmer, empiric data (both technical and price input) should be used to align with the true on-farm failure costs of production disorders.

As pointed out in chapter 3, total costs of production disorders do not only consist of failure costs. Farmers also apply measures to prevent the occurrence of production disorders. Insights in both failure and preventive costs provides valuable information because there is a substitution relationship between these costs which allows for costs optimization (McInerney, 1996; Hogeveen et al., 2019), i.e., finding a balance between failure and preventive costs where total costs are lowest. Therefore, in Chapter 3, both the failure costs and the preventive costs were estimated to determine the total costs of mastitis for individual dairy farms. Mastitis was used as a case study because it is the only disorder for which clear preventive measures have been defined (Huijps et al., 2010). Mastitis had, on average, the largest associated failure costs (Chapter 2) and has the highest occurrence (Table 1) in dairy herds. Similar to Chapter 2 empiric data (in this case only technical input) was used to reflect the actual total on-farm costs for mastitis. Comparable to the findings of Chapter 2 a large variation in failure costs between farms, ranging from 32 – 462 €/ cow per yr. Preventive costs made up a large part of the total costs of mastitis, varying between 48 – 180 €/ cow per yr., and should therefore not be neglected when estimating the total costs of production disorders. Nevertheless, based on the findings in Chapter 3 as well as findings from Aghamohammaddi et al (2018), it may be concluded that preventive costs of mastitis will remain incomplete. For example, some measures may have a direct impact on other production disorders such as cleaning lanes. In such a case attributing only part of the costs of such preventive measure to one disorder because of multiple effects makes it hard to economically account for when considering total costs of more production disorders at once, i.e., what part of the preventive costs are allocated to which production disorder. Furthermore, efficacy of preventive measures depends on the characteristics of the mastitis problem, where mastitis causing pathogens may be contagious or environmental in nature and where the symptoms may be more or less clinical (Huijps et al., 2010). Finally, the variation between farms having low failure costs and high preventive costs may reflect irrational investments made by the individual farmer, but may also reflect a snapshot of the situation, in which the herd was recovering from a mastitis problem. The proposed substitution relationship of McInerney et al (1992) and Hogeveen et al (2011) could not be confirmed for the studied group of farms. Based on our findings in Chapter 3 as well as earlier findings of Yalcin et al. (1999), this substitution relationship may only exist at the individual farm level, due to the substantial variation in herd level costs, disorder type and efficacy of various measures. Although, the background of these differences in the association between preventive and failure costs could not be explained, these farm-specific cost estimates, using empiric data, offer a starting point for discussion in the decision-making process.

Results of chapter 3 reveal that empiric data is required to evaluate the failure and preventive costs of individual farms. Nevertheless, it may be immensely difficult to evaluate the potential cost effectiveness of single measures. On a herd level the availability of cases for the measure to work may only be limited available or require a specific window of opportunity to be implemented (e.g. pain treatment of clinical mastitis post conception).

The efficacy of treatment over time could well be diluted by other farm management changes. The use of empiric data is, perhaps, desired to evaluate the economic impact of a preventive measure, as this links directly to the individual farm conditions, however the practical limitations prevent this from being possible. Therefore, to evaluate the potential benefits of a single preventive measure a farm-specific ex-ante analysis is required. Such an analysis can be done with a stochastic dynamic bio-economic model. In Chapter 4, a stochastic bio dynamic model at the cow level was developed to explore the effect of pain treatment of clinical mastitis and its effect on improved conception rates. Contrary to the use of empiric data in Chapter 2 and 3, in Chapter 4 I used general data entries. The model was based on the scientific work performed by McDougall et al. (2016) whereas the model dynamics were built to reflect actual Dutch farm conditions. Bio-economic modelling allows for integration of the complex variation in herd performance and impact of disorder and treatment and any uncertainty together with economic variations. The use of bio-economic modelling allows for an evaluation of the robustness of outcomes, hence, providing insights that are applicable to individual farmers. Furthermore, sensitivity analyses can be used to identify which farm-specific aspects have a strong influence on net results. For example, milk price as well as herd removal costs were important costs influencing the magnitude of the net results. Chapter 4 shows that the cost-effectiveness of the studied management measure is robust to a wide range of variations, both in terms of technical and price input, and thus generally concludes that the measure is an economically attractive measurement to implement on all farms. The use of a bio-economic model directly linked to empiric input has also been used by Burgers et al (2022) to evaluate different voluntary waiting periods. Hence, for evaluation of single management measures the use of bio-dynamic stochastic models based on empiric work is a valuable tool which supports animal health management and the decision-making process.

Farmers' resources are scarce and animal health management competes with other fields of management for these limited resources. No study to date has looked at farmers' preferences in animal health management in relation to other areas of management. The focus has always been on preferences within a specified area (e.g., Valeeva et al., 2007; Huijps et al., 2009a; Pothmann et al., 2014). Chapter 5 explores these overall farm management preferences and found substantial differences among farmers; some preferred field labour, while others preferred young stock management. Preferences varied between and within the evaluated countries but could not be explained through typical herd characteristics. The large number of clusters (7 for claw health and 9 for udder health) that resulted from the performed cluster analysis, did not define a clear type of farms or farmers that could explain certain preferences. Almost all studies on preferences, attitude and behaviour within the field of animal health management only considered a single production disorder (Kuiper et al., 2005; Swinkels et al., 2015; Babatunde et al., 2019; Shock et al., 2020). Such a limited approach may lead to a biased view on the relative importance of health management for a single disorder and the relevance of the production disorder in relation to other production disorders. Chapter 5 presents, as such, a first study exploring multiple health management areas against other farm management areas.

Most scientific work on production disorders has focused on increasing technical knowledge and estimating the economic impact of production disorders. In practice this information is used to convince farmers to start adopting advice. Several studies revealed that there are reasons other than economics or technical for not adopting animal health advise (Swinkels et al., 2015; Shock et al., 2020) which may be related to the farmers feeling (in)capable to control the disorder, perceiving the production disorder not as a problem or societal pressure on what should be done first. Each of these aspects may influence farmers' preferences towards various animal health management areas in relation to whole farm management, large variations in preferences have also been found in chapter 5 suggesting that such individual factors influence preferences. For health advisors such as veterinarians, being the most trusted advisor on animal health (Pothmann et al., 2014), it is important to consider that preferences are driving part of the decision process. Veterinarians unfortunately, have been shown to be not aligned on the of farmers goals and preferences on animal health (Derks et al., 2013) and therefore may also not be aware of any existing preferences regarding animal health. It is essential for veterinarians to understand the reasons why farmers make certain decisions and what preferences underly these reasons. Understanding farmers' decision making creates a background for dialogue, provides insights in which subject areas are important for the farmer and helps to aid decision support.

3. ANIMAL HEALTH MANAGEMENT FRONTIER

So far, much emphasis, both in scientific literature as well as the majority of this dissertation, has been on the failure costs of production disorders, indicating the economic impact of the disorders in comparison to situations without any disorders. In Chapter 3 a substantial variation in total costs of production disorders between farms was found. The evaluated lower bound on total costs was, however, always above zero. This finding was to be expected given the endemic nature of most production disorders, because eradication at farm level is deemed improbable. A hypothesis, initially proposed by McInerney et al. (1992; 1996), suggests that there is an optimal level of investment at which disease losses can be reduced, such that the sum of the disease losses and disease expenditures is the lowest. The hypothesis suggests that an over-investment in disease expenditures does not lead to further reduction of disease losses. In other words: maximum disease expenditures will lead to minimum disease losses, but this situation may not be the economic optimum. McInerney's hypothesis has later been adapted more specifically to dairy cow production disorders by Hogeveen et al (2011), by suggesting a substitution relationship between failure costs and preventive costs. Such a relationship allows for optimization of preventive measures, i.e. indicating the existence of an economic optimal point at which the total costs, a sum of failure and preventive costs is at a minimum. Based on the work presented in this dissertation (Chapter 3) I can conclude that there is no uniform relationship between failure costs and preventive costs for groups of farmers. Most likely due to structural, managerial and technical differences between farms. If there is a substitution relationship between failure and preventive costs, it must be farm specific.

Current on-farm data collection is sufficient to estimate failure costs of production disorders (Chapter 2 and 3). Nevertheless, data collection is insufficient to estimate the preventive costs in such a way that all relevant management actions are taken into account and valued accordingly, as pointed out in Chapter 3. Combined with the lack of comparability of failure costs, typically presented in scientific literature, it is hard for farmers to evaluate which investments make most sense from an economic perspective. Therefore, to support the specific on-farm animal health decision making process I propose a new concept, based on the aforementioned hypotheses of McInerney et al. (1992; 1996) and Hogeveen et al (2011). This concept proposes a relationship between failure costs and preventive efforts following a downward convex curve for each production disorder, thereby aligning with the diminishing marginal returns proposed by McInerney et al. (1992; 1996) and Hogeveen et al (2011). In this concept, each production disorder is represented by a separate curve fitted to the conditions of the individual farm. The combination of curves for multiple production disorders is what I call the Animal health management frontier. Furthermore, since preventive costs, are difficult to estimate on the individual farm level, I propose the use of an ordinal measure of preventive effort instead of an actual estimation on preventive costs. Use of this animal health frontier concept should lead to more specific on-farm insights, such that it:

1) Creates insights in the actual on-farm failure costs

2) Allows for a direct comparison between different production disorders

3) Reveals which part of the failure costs can be reduced for the different production disorders, and

4) Indicates for which production disorder additional preventive measures deliver the highest returns

To translate the animal health management frontier concept into a practical application, the following steps are needed:

1) Collect all relevant data required to estimate the current farm failure costs in line with the data collection process of Chapter 2. Thus including technical parameters, such as herd size, production levels, production disorder incidences, culling, treatment records and price levels. Such data is routinely collected and when data collection programmes are regularly updated, collection should not take much time. Farmers should be free to provide own estimates, but they should be given reference values for complex price components such as replacement and rearing costs.

2) Collected farm data should be used to construct individual failure cost estimates of multiple production disorders. These failure costs represent the current failure costs of the individual farm.

3) Preventive effort is defined as the relative effort made by the farmer to reduce production disorder incidence on a farm. The preventive effort is expressed on a 7-point Likert scale in which 1 means ‘do nothing’ and 7 means ‘every possible effort is made’. Farmer and veterinarian should align on how much effort is currently made to prevent any of the production disorders from occurring, by setting

an ordinal scale value for each of the production disorders. These values represent the current preventive effort.

4) To be able to construct a curve between failure costs and preventive effort of a particular production disorder, two more data points are required. The hypothetical maximum failure costs when a farmer makes no preventive effort to control a production disorder. Similarly, the minimum failure costs when a maximum preventive effort is made to control the production disorder need to be estimated. Realistically, this latter number will always be nonzero as production disorders almost always occur. Maximum and minimum numbers cannot typically be derived from herd health recordings, as farms are always implementing measures to control production disorders. Therefore, farmer and veterinarian should align on how technical parameters are influenced when a farmer would operate at the far ends of the scale.

5) For both the minimum and maximum preventive effort data points, described in step 4, the related failure costs can be estimated indicating the minimum and maximum failure costs.

Based on the approach described above curves for different production disorders can be fitted to the different data points to construct the animal health frontier. An example of the application of the animal health frontier approach is presented in Figure 1. It demonstrates the frontier of mastitis and ketosis, revealing the current position and impact on failure costs by increasing efforts one step up the scale. In the example, the marginal returns from increasing preventive effort by one scale would yield €800 / farm per yr. for ketosis (scale 2 to 3) and €480 / farm per yr. for mastitis (scale 4 to 5). Hence, from an economic point of view, the farmer should allocate resources towards ketosis management before addressing mastitis. Furthermore, any increase in preventive effort after scale three results in lower marginal returns with respect to ketosis than with respect to mastitis.

One of the primary assumptions made in the construction of this frontier is that with respect to the use of the ordinal scale to measure effort, the units are equidistant (this effectively implies a cardinal/interval scale) and assessments of efforts are made as such. This means that moving between any two values on this scale equates to the same magnitude of change in actual effort for different assessors. This might not be the case in reality. Failure to comply with this assumption will classify a farmer in the wrong effort scale and consequently assuming incorrect levels of marginal returns from increasing preventive effort. Similarly, the problem with non-equidistant scaling has been pointed out in the studies by Engel et al. (2003) and Thomsen et al. (2008) in which the same lame cow was classified in different categories of the ordinal scale of the lameness scoring system by different assessors. This clarifies that the system of scaling relies on the capacities and experience of the assessor. There does not seem to be a clear solution for this problem, although one possible solution would be to translate preventive notional effort into actual preventive costs. This would, however, require much more farm specific data on what is currently being done to control production disorders and an assessment of the maximum attainable level of expenditures on preventive measures, which is on a farm-by-farm basis. In practice, such information is not available, and it is questionable if the derived data would yield better insights. Especially, if it is the aim of the frontier is to compare between production disorders. The proposed Animal health frontier is suitable to fit with the current data collection at the farm level and I expect that it contributes to a more insightful decision making. Nevertheless, the preventive effort is a subjective evaluation by both farmer and veterinarian and may be prone to bias as discussed above. The value of the animal health frontier lies in the fact that it provides a focus on which part of the failure costs can actually be reduced at the individual farm level. Thereby it reflects on the consequences and the potential gains when altering preventive efforts on production disorders. It serves as a first exploration before deep diving into what management measure(s) should be applied.

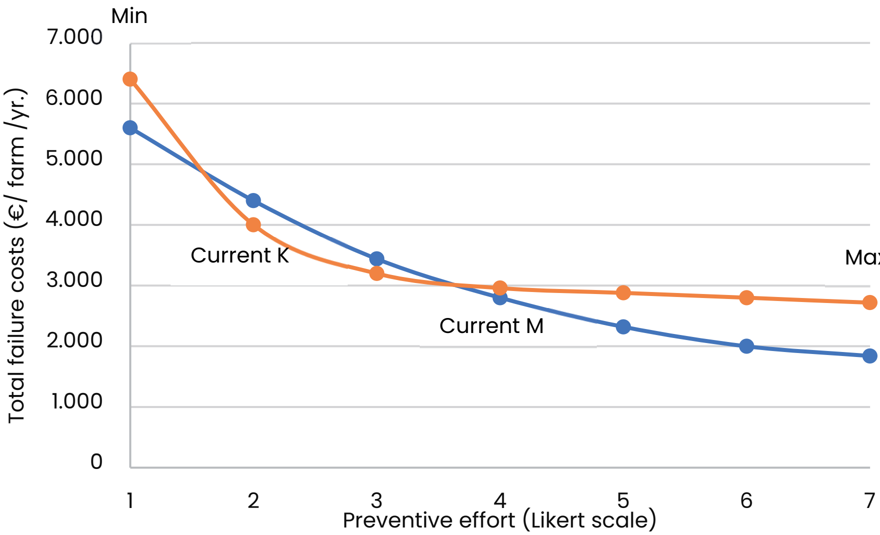

Figure 1. Animal health frontier containing two hypothetical curves for Mastitis (Blue) and Ketosis (Green), Minimum and maximum denoting the minimum and maximum preventive effort and associated total failure costs and Current K (ketosis) and M (mastitis) denoting the current farm situation.

4. PREFERENCES OF INDIVIDUAL FARMERS

This dissertation has focused primarily on eliciting the economic impact of a decision the farmer could make to manage production disorders. The proposed concept mentioned in the previous section can be a significant step forward (also in conceptual thinking) when it comes to supporting decisions within the animal health domain as it reveals potential gains from a reasonable improvement (marginal returns). Nevertheless, it is often assumed that farmers make economic rational decisions and implement change when, out of the available options, one option elicits the largest increase in financial gain or the highest return on investment. In reality, we may find that farmers not necessarily follow the animal health advice with the highest economic benefit (Hansen and Greve, 2014; Lam et al., 2017; Graskemper et al., 2022). In Chapter 5 farmers' preferences for herd health management were elicited in relation to other areas of management. The preference for herd health management was generally lower compared to other areas of management. To aid decision support it is important to understand which limitations farmers experience when making their management decisions. Some limitations may have a financial origin (insufficient cash flow), technical (barn design or management system) or a mental origin (perception of own abilities, opinions of others or perceived efficacy) (Babatunde et al., 2019; Shock et al., 2020). Hence the herd health management should not be considered in isolation as it is competing with other fields of management. In Chapter 5, the adaptive conjoint analysis technique was used to elicit preferences for management areas. The main advantage of this approach is that it produces utility scores per management area that can be translated into preferences, the attribute with the highest utility score represents the most preferred management area. In theory, comparable methods and tools can be used in field conditions to elicit the preferences for various herd health management aspects. These techniques, however, require more in-depth knowledge and specific training to be successfully applied and take time to complete. I, therefore, propose to make behavioural studies - such as the ones mentioned above - a focus for further study as the outcomes of such work can be used as conversation material for a discussion on goals, attitudes and preferences, and serve as a step forward in discussions between farmer and veterinarian.

One interesting path for further study should be, and it has not been done before in such a way, to estimate the willingness to pay (WTP – at what price a person would buy a product/service) for animal health advice or animal health management interventions. I believe this is an essential field for further research, because many farmers claim that the technical knowledge they need is already available (Swinkels et al., 2015; Shock et al., 2020). This is confirmed by a short search on the Web of Science where a search for studies on dairy production disorders resulted in a excess of studies on pathogenesis, epidemiology, control, intervention and efficacy of measures (2,411 results) and even economic impact (129 records) to which this dissertation contributed significantly. To my knowledge, only one study has so far come close to estimating the WTP for animal health intervention (Peden et al., 2019). Interestingly, it has been suggested that WTP studies outcomes also include and reflect preferences (Horowitz and McConnell, 2003) and thus integrate both financial and non-financial motives in one measure.

Finally, a willingness to accept study (WTA - at what price a person would sell a product/service) among veterinarians would be interesting. This would elicit what a veterinarian finds a reasonable sum for which they would sell their management advice. Horowitz and McConnell (2003) found that the ratio WTA/WTP was on average 7, which would mean (if true) in our situation that the price a veterinarian finds acceptable for an animal health management intervention is seven times higher than what a farmer is willing to pay for the intervention. Such studies are to date not performed on animal production disorders in dairy cattle but could substantially contribute to a better understanding of the decision-making process of the farmer and perhaps explain why certain advice is not followed.

5. CONCLUSION

This dissertation obtained farm specific insights in 'how-to' manage dairy cattle production disorders from an economic perspective to support the farmer's decision-making process. Based on the main results of the research presented, the following conclusions and recommendations are drawn

Conclusions

- Failure costs for production disorders vary substantially between different farms. To aid the decision support on productions disorders, failure costs of production disorders should therefore be assessed for individual farms (Chapter 2)

- Ignoring the economic impact of preventive measures leads to an underestimation of the costs of production disorders. Farmers vary substantially in the preventive measures they apply, indicating farm specific management considerations. Moreover, preventive costs are difficult to assess completely (Chapter 3).
- To generate better insights in the contribution of preventive measures in reducing failure costs bio dynamic stochastic modelling can be applied. In combination with the use of empiric input and scenario analysis it can contribute to robust and realistic outcomes which can be used to support management on individual farms (Chapter 4).
- Animal health management is important to dairy farmers and may conflict with other areas of management, hence influencing the decision process. External advisors such as veterinarians need to be aware of farmer's preferences to better understand the decision making (Chapter 5)

Recommendations

- Future work should be carried out on which part of the failure costs can actually be reduced, the Animal health frontier approach as proposed in this dissertation could be a method to explore this.
- More research needs to be done into the willingness to pay in terms of animal health to reveal how much a farmer is willing to invest in preventive measures.

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Chapter 6

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Summary

Acknowledgements

About the author

List of publications

Training and supervision plan

Summary

Production disorders on dairy farms include animal diseases or health states which are directly linked or impacted by to the production of milk and negatively impact animal performance and/or farm profitability. Main production disorders include mastitis, ketosis, lameness and metritis. The financial impact of each of these production disorders is substantial and, in general, is caused by decreased milk production, treatments (drugs, labour and discarded milk) and early herd removal. The costs associated with these production disorders are the so-called failure costs, reflecting the economics effects due to the fact that the animal fails to reach its full production potential. To date most failure cost calculations in scientific literature focus on estimating the 'generic' case of a production disorder using 'generic' assumptions either on technical data (such as milk production levels) and/or price input. As a consequence, they refer to the average farms within a production system. When it comes to supporting the decision-making process on the individual farm such outcomes may be experienced as too generic, which creates a discrepancy between estimated failure costs and true on-farm failure costs. Moreover, farmers also invest resources in preventing production disorders, but the economic impact of such preventive management measures has hardly been explored. The overall aim of this dissertation was therefore to gain farm specific insights in 'how-to' manage dairy cattle production disorders from an economic perspective to support the farmer's decision-making process.

The overall objective was achieved by studying the following research questions:

- Can we tailor the failure costs for multiple production disorders such that they reflect the individual farm conditions and that they can be directly compared with each other?
- What is the relation between failure and preventive costs associated with a production disorder on individual dairy farms?

- Can the economic impact of a preventive management intervention on a production disorder be evaluated, such that it takes into accounts the individual conditions of farms?
- Which priority do farmers give to animal health management in relation to other management areas?

On-farm decision support in animal health management requires a tailor-made failure costs (FC) assessment of production disorders for the individual farm. In Chapter 2, a generic framework is defined to estimate the FC of production disorders in dairy cows. The framework is converted to a practical tool in which the farm-specific FC of mastitis, ketosis, lameness and metritis are estimated for 162 organic dairy farms in four European countries. Along with the structure of the framework, the tool requires three distinct types of model input: performance input (relating to herd performance parameters), consequential input (related to the consequences of the production disorders) and economic input (related to price levels). Input was derived from official herd recordings (e.g., test-day records and animal health recordings) and farmers' responses (e.g., questionnaire replies). The average FC of mastitis, ketosis, lameness and metritis amounted €96, €21, €43 and €10/ cow per year, respectively. FC outcomes were highly variable between farmers, indicating the need for farm specific estimates to to rank production disorders in terms of their associated failure costs, providing valuable insights for herd specific health management. Overall ranking of the production disorders based on absolute values was the same for all countries, with mastitis being the costliest production disorder followed by lameness, ketosis, and metritis. The tool developed in this study should be considered by farmers or herd health advisors to support their animal health practices or advice.

Mastitis is an important production disorder from an economic perspective, but most cost assessments of mastitis include only the direct costs associated with the production disorder (e.g., production losses, culling, and treatment), indicating failure costs (FC). However, farmers also invest time and money in controlling mastitis, and these preventive costs (PC) also need to be taken into account. In Chapter 3, both FC and PC were estimated to estimate the total costs of mastitis Multiple test-day milk records from 108 Dutch dairy farms were combined with information on applied mastitis prevention measures and farmer's registration of clinical mastitis for individual dairy cows. The aim was to estimate the total costs of mastitis and to give insight into variations between farms. The average total costs of mastitis were estimated at €240/ lactating cow per year, in which FC contributed €120/ lactating cow per year and PC contributed another €120/ lactating cow per year. Milk production losses, discarded milk, and culling were the main contributors to FC, at €32, €20, and €20/ lactating cow per year, respectively. Labor costs were the main contributor to PC, next to consumables and investments, at €82, €34, and €4/ lactating cow per year, respectively. The variation between farmers was substantial, and some farmers faced both high FC and PC. This variation may have been due to structural differences between farms, different mastitis-causing pathogens, the time at which preventive action is initiated, stockmanship, or missing measures in PC estimates. Minimum FC were estimated at €34/ lactating cow per yr. All farmers initiated some preventive action to control or reduce mastitis, indicating that farmers will always have mastitis-related costs, because mastitis will never be fully eradicated from a farm. Insights into both the PC and FC of a specific farm will allow veterinary advisors and farmers to assess whether current udder health strategies are appropriate or whether there is room for improvement from an economic perspective.

Recently, it has been shown that the addition of meloxicam to standard antimicrobial therapy for clinical mastitis (CM) improved the conception rate of dairy cows contracting CM in the first 120 days in milk. The objective of the presented study in Chapter 4 was to assess whether this improved reproduction through additional treatment with meloxicam would result in a positive net economic benefit for the farmer. A stochastic bio-economic simulation model was developed, in which a dairy cow with CM in the first 120 days in milk was simulated. Two scenarios were simulated in which CM cases were treated with meloxicam in conjunction with antimicrobial therapy, or with antimicrobial therapy alone. The scenarios differed for conception rates (31% with meloxicam or 21% without meloxicam) and for the cost of CM treatment. Sensitivity analyses were undertaken for the biological and economic components of the model, to assess the effects of a wide range of inputs on the inferences about the cost effectiveness of meloxicam treatment. Model results showed an average net economic benefit of €42/ CM case per year in favour of the meloxicam scenario. Although cows in the non-meloxicam treatment scenario had higher returns on milk production, lower costs upon calving and reduced costs of treatment; these did not outweigh the gains in lower feed intake, reduced number of insemination and the reduced culling rate. The net economic benefit favouring meloxicam therapy was a consequence of the better reproductive performance in the meloxicam scenario in which cows had a shorter calving to conception interval (132 vs. 143 d), a shorter inter-calving interval (405 vs. 416 d) and fewer AI per conception (2.9 vs. 3.7) compared to cows in the non-meloxicam treatment scenario. This resulted in a shorter lactation, hence a lower lactational milk production (8,441 vs. 8,517 kg per lactation) with lower feeding costs in the meloxicam group. A lower culling rate (12% vs. 25%) resulted in lower replacement costs in the meloxicam treatment scenario. All of the scenarios evaluated in the sensitivity analyses favored meloxicam treatment over no meloxicam treatment. This study demonstrated that improvements in conception rate achieved by the use of meloxicam, as additional therapy for mild to moderate CM in the first 120 days in milk, have positive economic benefits. This inference remained true over a wide range of technical and economic inputs, demonstrating that use of meloxicam is likely to be cost-effective across many production systems.

The expertise and knowledge of veterinary advisors on improving animal health management is key towards a better herd health status. However, veterinary advisors are not always aware of the goals and priorities of dairy farmers. To dairy farmers animal health is only one aspect of farm management and resources may be allocated to other more preferred areas. Veterinary advisors may experience this as non-compliant with their advice. To explore the preferences of EU organic dairy farmers for improved animal health management relative to other farm management areas an adaptive conjoint analysis was performed (Chapter 5). A total of 215 farmers participated originating from organic dairy farms in France (n=70), Germany (n=60), Spain (n=28) and Sweden (n=57). The management areas udder health and claw health represented animal health management whereas barn, calf and pasture management represented potential conflicting management areas. Results indicate that EU organic dairy farmers differ in their preferences for improved animal health management within the farming system. In general, improved calf management was the most preferred area and improved claw health management was found to be least preferred, the remaining areas were of intermediate interest. Cluster analyses on claw health measures and udder health measures resulted in, respectively, seven and nine distinct preference profiles. The results indicate a high degree of variation in farmers' preference, which cannot be explained by the typical herd characteristics. With the individual preferences revealed by ACA, a veterinary advisor can now find out whether his intended advice is directed at a favourable or unfavourable management area of the farmer. If the latter is the case the veterinarian should first create awareness of the problem to the farmer. Insights in individual farmers preferences will allow veterinary advisors to better understand why farmers were incompliant with their advice and improve their advice by showing e.g., the potential benefits of their advice.

In the concluding Chapter 6 the results, data and methodological approaches are synthesized, and final conclusions drawn. This chapter introduces a novel concept the animal health frontier which suggests a substitution relationship between failure costs and preventive effort made to control a production disorder. The animal health frontier allows for a direct comparison between the failure costs of multiple production disorders present at the farm level and has a strong focus on which part of the failure costs may realistically be reduced. Thus, allowing farmers to make trade-off decisions between different production disorders for which the results reflect the individual farm. Finally, I argue that there has been a strong focus on failure cost estimations of production disorders, but to date no focus has been on what a farmer is willing to pay to actually control the production disorder.

Based on the main results of research, the following main conclusions are drawn:

- Failure costs for production disorders vary substantially between different farms. To aid the decision support on productions disorders, failure costs of production disorders should therefore be assessed for individual farms (Chapter 2)
- Ignoring the economic impact of preventive measures leads to an underestimation of the costs of production disorders. Farmers vary substantially in the preventive measures they apply, indicating farm specific management considerations. Moreover, preventive costs are difficult to assess completely (Chapter 3).
- To generate better insights in the contribution of preventive measures in reducing failure costs bio dynamic stochastic modelling can be applied. In combination with the use of empiric input and scenario analysis it can contribute to robust and realistic outcomes which can be used to support management on individual farms (Chapter 4).
- Animal health management is important to dairy farmers and may conflict with other areas of management, hence influencing the decision process. External advisors such as veterinarians need to be aware of farmer’s preferences to better understand the decision making (Chapter 5)

And the following recommendation are made:

- Future work should be carried out on which part of the failure costs can actually be reduced, the Animal health frontier approach as proposed in this dissertation could be a method to explore this.

- More research needs to be done into the willingness to pay in terms of animal health to reveal how much a farmer is willing to invest in preventive measures.

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ik het laatste half jaar weer eens een dagje vrij nam om aan mijn proefschrift te werken, beter gezegd mijn 'werk' naast het werk. Vincent, dank voor jouw steun en begrip hierin.

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"Soms denk ik uren na en heb ik nog niks op papier, een andere keer bereik ik precies datzelfde in vijf minuten" H. Finkers

About the author

Felix Johannes Sijmen van Soest was born on November 11, 1986 in Rhenen, the Netherlands. He grew up in Veenendaal and graduated from the Christelijk Lyceum Veenendaal in 2006. He obtained his BSc degree in Animal Sciences at Wageningen University. In 2012 he started his MSc Animal Sciences also at Wageningen University, with a specialization in Quantitative Veterinary Epidemiology. Felix conducted his minor thesis at the Business economics group, working on the failure and preventive costs of mastitis on Dutch dairy farms, a study which was later published in Journal of Dairy Science and part of this dissertation. During his internship at the animal health service (Gezondheidsdienst voor Dieren, Deventer, the Netherlands) in the Netherland he studied the risk factors associated with increased mortality in dairy calves. His major thesis was at the quantitative veterinary epidemiology group, studying the survival of Dutch dairy cows after removal of a tyloma (Interdigital Phlegmon).

After graduation Felix started as PhD candidate at the Business economics group at Wageningen University. His research was part of a larger EU funded 7th Framework Project called IMPRO, and focused on the economic impact of production disorders in dairy cows. During his time at the Business economics group he supported multiple courses as teaching assistant and supervised MSc students. In 2017 Felix was appointed as teacher at the same chair group and taught, organized and supervised the course sustainable seaweed chains.

From June 2017 Felix accepted a role as Technical Account Manager Benelux at Biochem GmbH being responsible for the sales of the feed additive portfolio, which were primarily being sold to Dutch and Belgian feed millers. In his function he organized seminars, was responsible for strategic account plans, facilitated technical trainings at the customer side and initiated field trials.

In May 2019 Felix started a position as technical specialist Feed Additives Monogastric at Trouw Nutrition Benelux. At Trouw Nutrition Felix was responsible for the technical support of the feed additive portfolio, ranging from enzymes, pro- and prebiotics, organic acids to phytogenics, to both the technical team and sales team. Next to this he focused on strategic positioning of the feed additives, identifying market opportunities and conceptualization for our market solutions. From august 2022 onwards Felix became technical specialist Feed Additives Poultry & Aqua at Trouw Nutrition Benelux Scandinavia France, in which he now focuses more specifically on these market segments, maintaining the same product portfolio and responsibilities.

List of publications

Blanco-Penedo, I., Sjöström, K., Jones, P., Krieger, M., Duval, J., van Soest, F., Sundrum, A., & Emanuelson, U. (2019). Structural characteristics of organic dairy farms in four European countries and their association with the implementation of animal health plans. Agricultural Systems, 173. https://doi.org/10.1016/j.agsy.2019.03.008

Steeneveld, W., Amuta, P., van Soest, F. J. S., Jorritsma, R., & Hogeveen, H. (2020). Estimating the combined costs of clinical and subclinical ketosis in dairy cows. PLoS ONE, 15(4). https://doi.org/10.1371/journal.pone.0230448

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van Soest, F. J. S., Santman-Berends, I. M. G. A., Lam, T. J. G. M., & Hogeveen, H. (2016). Failure and preventive costs of mastitis on Dutch dairy farms. Journal of Dairy Science, 99(10). https://doi.org/10.3168/jds.2015-10561

Training and supervision plan

Felix Johannes Sijmen van Soest
Wageningen School of Social Sciences (WASS)
Completed Training and Supervision Plan

Wageningen School of Social Sciences

Name of the learning activity	Department/Institute	Year	ECTS*
A) Project related competences			
Advanced econometrics (YSS34306)	WUR	2014	6
Economic models (AEP-30806)	WUR	2014	6
Applied economic modelling for the veterinary sciences	UU graduate school life sciences	2013	2
Econometrics (AEP21306)	WUR	2013	6
B) General research related competences			
Introduction course	WASS	2016	1
PhD research proposal	WUR	2013	6
'The costs of dairy production disorders in European practise; over- or underestimated?'	29th World Buiatrics conference, Dublin	2016	1
'Economic benefit of an improved conception rate in dairy cows though additional treatment of mastitis with meloxicam'	56th annual NMC meeting, St Pete Beach, Florida	2017	1
'Cost and benefits of mastitis management measures on individual Dutch dairy farms'	15th international conference on production diseases in farm animals	2013	1
'European organic dairy farmers preference for animal health management within the farm management system'	26e studiedag VEEC, Dutch society for veterinary epidemiology and economics	2014	1
BEC PhD meetings	WUR	2012 - 2016	2

C) Career related competences/personal development

Teaching and supervising - Sustainable seaweed chains BEC53806 - Introduction to Business Economics. Management and Marketing BEC21806 - Veterinary Epidemiology and Economics QVE20306 - Student thesis supervision – Economic impact of breeding for longevity in dairy cows	WUR	2012 - 2016	4
Total			**37**

*One credit according to ECTS is on average equivalent to 28 hours of study load

Colophon

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