Farm-specific failure costs of production disorders in European organic dairy herds

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Short title: Farm specific failure costs of production disorders

Abstract

On-farm decision support in animal health management requires a tailor-made failure costs (FC) assessment of production disorders for the individual farm. In our study we defined a generic framework to estimate the FC of production disorders 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 FC estimation required three distinct types of model input: performance input (related to herd performance parameters), consequential input (related to the consequences of the 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 to €96, €21, €43 and €10 per cow per year, respectively. The variation in FC outcomes was high among farmers and countries. Overall ranking of the disorders based on absolute values was the same for all countries, with mastitis being the costliest disorder followed in order by lameness, ketosis, and metritis. Farm specific estimates can be used to rank production related disorders 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.

Keywords: animal health economics, mastitis, ketosis, lameness, metritis

Implications

This study shows that empirical data can be used to estimate the on-farm economic impact of multiple production disorders. Tailor-made costs estimates can be used to rank production-related disorders in terms of their associated failure costs and thus provide valuable insights for herd health management. In general, mastitis remains the most costly production disorder on European organic dairy farms. Nevertheless, costs estimates of other production disorders (lameness, ketosis and metritis) are considerably high and may even be more costly than mastitis on individual farms.

Introduction

Keeping animals healthy is one of many management areas that requires attention in dairy farming. Although animal health management is deemed important by dairy farmers (Jones et al., 2016; Valeeva et al., 2007; Van Soest et al., 2015) conflicts arise when other management areas compete for the available resources of time, labour and finance. Within the animal health management area, similar conflicts also arise when farmers must decide where to allocate their restricted resources to maintain a healthy herd in the most effective way (Singer et al., 2011). This is a complex decision considering that cattle can become affected by different health disorders, with each disorder having its own characteristic symptoms and impact. The most prevalent health disorders on EU dairy farms are endemic and production related. The demand for high productivity may increase incidence levels further (Fleischer et al., 2001; Gröhn et al., 1995; Vanholder et al., 2015). Common production-related health disorders (in the remainder of this manuscript presented as production disorders) include: mastitis, ketosis, lameness and metritis which have been reported at average incidences of 28%, 47%, 69% and 69%, respectively (Lam et al., 2013; Urton et al., 2005; van der Linde et al., 2010; Vanholder et al., 2015). Each of these disorders affects the overall herd performance through a decrease in production level or an increase in health treatments, labour requirements and involuntary herd removal. The costs associated with this reduced herd performance are referred to as failure costs (**FC**) (Hogeveen et al., 2011). The FC of mastitis, ketosis, lameness and metritis within conventional dairy farms have been reported at the range of € 87 - € 946 per case (Cha et al., 2011;

Heikkilä et al., 2012; Liang et al., 2017), € 72 - € 442 per case (McArt et al., 2015; Mostert et al., 2017; Raboisson et al., 2015), € 106 - € 291 per case (Bruijnis et al., 2010; Cha et al., 2010; Liang et al., 2017) and € 92 - € 230 per case(Bartlett et al., 1986; Liang et al., 2017), respectively. Variations in costs estimates depended on factors such as form (clinical or subclinical), pathogen and severity.

General farm performance as indicated by milk production levels and price levels (like for instance of milk and concentrate), vary 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 farm specific due to the use of empirical data, all other economic studies on the FC of production disorders were based on simulation modelling (e.g., Swinkels et al., 2005; Halasa et al., 2009a; McArt et al., 2015). The simulation models within these studies represent most of the time a generic farm, assuming average settings with respect to herd size, incidence level, production level and price levels. These generic settings make a direct comparison of FC between multiple disorders almost impossible on the individual farm level. To set priorities within the animal health management area farmers require FC estimates for the various disorders in which their specific farm situation is represented and comparisons between disorders can be made. Although the economic and technical input used for economic calculations vary largely per disease the actual cost components involved of the various disorders are for the major part the same. This allows the development of a generic framework to structure and compare the economic impact for each disorder. At the same time transparency to the farmer (i.e., the decision maker) on both model in- and output should be warranted to guarantee the credibility of the estimations made.

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). In practice, the animal health status on organic dairy farms is, on average, not better than in the conventional sector (Hovi et al., 2003; Sundrum, 2001; Sutherland et al., 2013; van Wagenberg et al., 2017). A high animal health status in organic farming is therefore crucial to comply with consumer expectations to ensure the milk price premium organic farmers are receiving. Occurrence of one or more production disorders directly affects farm income through increased health treatments. Other, more indirect effects, are less visible considering that the associated effects are less immediate or notable to the dairy farmer, such as increased involuntary replacement 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 disorders considering that multiple production disorders often occur simultaneously. Economic assessment of the current disorder 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 an outlook on which production disorder may be prioritised over another.

Consequently, the aim of our study was to estimate the farm specific FC of mastitis, ketosis, lameness and metritis on European organic dairy farms, by using readily available farm data, and to explore the variation in FC between and within EU countries for the different disorders.

Material and methods

A general framework was developed to estimate the FC of production disorders 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 incidence 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 disorders

The framework to estimate the FC of production disorders is presented in Figure 1. To estimate the FC we were interested in the marginal effect of each production disorder 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 disorder were included (Dijkhuizen and Morris, 1997). In our study FC consisted of three main cost elements: milk production losses, treatment and herd removal. Milk production losses included the losses associated with, both, the clinical and subclinical forms of a disorder. 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). Herd removal included the involuntary removal (slaughter) or death of an animal as a result of a disorder. Table 1 provides an overview of the evaluated production disorders, their associated case definitions and affected cost elements (milk production loss, treatment and/or herd removal) FC estimations for each disorder were aggregated as the available empirical information lacked insights on the underlying aetiology of observed cases.

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. Appendix A provides a more detailed description of the calculations performed. The FC estimations are assumed multiple exclusive, e.g. no interaction between the disorders is assumed, and FC are estimated separately for each disorder. To prevent double counting of the economic losses the FC of the different disorders cannot be summed to estimate the total economic impact of all disorders to farm income. This assumption was required because data was available on herd level only, missing the information on animals suffering from multiple disorders at the same time. For instance, one cow could attract both clinical mastitis and subclinical ketosis at the same time. In such a case the associated milk production loss is expected to be lower than the summed amount due to each disease separately. Estimated FCs can therefore only be used to compare the costs among the disorders and hence provide insight to which disorder to address management resources first.

Application of the tool to assess the indicated FC costs elements requires three types of input: input on the performance of the herd, input related to the consequences of the disorder and economic input on price levels. Performance input relates to the performance of the herd and includes: the number of clinical and subclinical cases[1] of a disorder, the number of dead or removed cows due to the disorder, average milk production per cow per year (kg milk per cow per year) and average milk production

[1] The number of cases reflects the number of individual animals affected by the disorder

per cow per day (kg milk per cow per day). Input related to the consequences of a disorder includes: average 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[2], average labour requirements to treat a clinical case (hour per treated case) and percentage of clinical cases which require a veterinary visit. Economic input relates to the on-farm price levels and includes: the price of milk (€ per kg milk), feed costs (€ per kg milk), average price per conventional treatment[3], average price per alternative treatment, average price of a veterinary visit, labour costs (€ per hour), average replacement costs (€ per removed or dead animal), costs of destruction (€ per dead animal) and average 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 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[4]). The organic dairy farms participating in this project represented the variation found in size, share and degree of settlement of organic development of

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[2] Conventional therapy included: the general recommended veterinary therapy to treat the animal, may include the application of antibiotics if appropriate.
Alternative therapy included: any treatment generally perceived as non-conventional to treat animals and may include homeopathy, phytotherapy or allopathy, None of these treatments involved a withdrawal period for milk.
[3] Average costs related to the treatment of an individual case, accounting for any retreatment costs
[4] Developed tool available on http://www.impro-dairy.eu/index.php/outreach/economic-tool

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. (2015), Krieger et al., (2017) and Jones et al (2017). Moreover, technical model input used in this study, differences between countries and standardisation of the various data collected has been described and discussed thoroughly in Krieger et al. (2017).

Parametrisation: stage 1

Input was derived from various data sources: herd recordings, literature and information directly obtained from the farmer. 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 disorder incidence levels, and test-day milk recordings, and was initially collected for the purpose of other research aims within the IMPRO project and described and discussed by Krieger et al. (2017) and used as primary input for this study. 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 incidence was derived from herd health recordings (Krieger et al., 2017). The remaining herd recorded data needed to be processed first. The milk production data were 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-date record 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 (Halasa et al., 2009; Huijps et al., 2008). 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 (Čejna and Chládek, 2005; Duffield et al., 1997; Krogh et al., 2011). All performance related input is presented in Table 2.

Technical input relating to disorder impact was derived from scientific literature, manufacturers' norms or authors expertise (Table 3), the most recent country specific professional journals indicating price levels for each country and was cross validated by researchers from each respective country participating in this study (Table 4). Each of these parameters were administered to the tool as part of stage 1 of the parametrization.

Due to the specific nature of each disorder specific changes to the framework were required for some cost components. Milk production losses associated with ketosis were estimated for cows with a disturbed FPR which was assumed to include clinical and subclinical cases of ketosis, as the provided data was on herd level. Additional milk production losses associated with farmers identified clinical ketosis cases were excluded to prevent overestimation of milk production losses associated with ketosis (Table 3). The farmers identified cases were used to calculate the economic losses of herd removal and treatment. Production loss estimates of mastitis, included both clinical and subclinical production losses which is due to the specific nature of both disorders and moment of occurrence (Barkema et al., 1998; Suthar et al., 2013). Milk production losses associated with early 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 late metritis. Within the FC cost calculation of metritis losses due to subclinical forms were not accounted for due to the lack of readily available case indicator. Detection of subclinical metritis is generally done by measuring polymorphonuclear neutrophils or through ultrasonography of the uterus (Kasimanickam et al., 2004; Lenz et al., 2007), which are rather time consuming methods that require the expertise of an experienced veterinarian. 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 disorder was the amount of labour required to fully service one case of the disorder. Data derived from literature was either used for the consequential data input or to set reference price levels.

Parametrisation: stage 2

Data missing or not-available from either official herd recordings or literature were 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 send 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 preliminary questionnaire included questions regarding price levels, herd removal, disorder incidence levels and applied treatments. More specific, farmers were requested to indicate how many of their cows were treated for ketosis (incidence of clinical ketosis), early metritis (incidence of metritis) and late metritis (incidence of late metritis). Furthermore, farmers were asked to indicate the number of cows culled for mastitis, lameness, ketosis and metritis, separately, and to do the same for the number of cows dead on the farm. Thereafter the total number of dairy cows that were replaced or died during last year was questioned to assess the overall average herd replacement rate. 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 4.

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. Furthermore the farm's veterinarian was present to ensure validation of input data.

Based on the collected herd record data (Table 2) and literature data (Tables 2) and assumed price levels (Table 4) 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 preliminary 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 3) was used. Finally, FC were calculated for each individual disorder 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 disorder varied among countries. Furthermore, the relative ranking of disorders within a country was tested to determine whether the relative order varied among countries. Finally, a correlation analysis was performed to explore how the FC of one disorder may affect in- or decrease of other FCs.

Results

Descriptive statistics

Herd performance. Herd performance results are presented in Table 2. Herd size and milk production were found to be highly variable among 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 annual incidence 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 disorders. One Spanish farm reported an annual incidence 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 annual incidence 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 annual incidence 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 early and late metritis, 58 farms indicated no occurrence of one of these disorders. Out of these, on 35 farms both early and late metritis 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 herd removal rate as a result of one of the four disorders was 10%, however, a total of 15 farms reported total herd removal rates larger than the replacement rate suggesting that some cows were removed due to a combination of disorders. This was not further scrutinized.

Consequences of a disorder. With the exception of one change made by a German farmer, no changes were made to the input related to the consequences of a disorder. 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 4. Reasons for changing the reference value were not asked to the farmers. No Spanish farmer indicated that he 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. Such changes may be depend on local regulation or contracts with various dairy companies to which the milk was delivered.

Failure costs

Failure costs for all of the four disorders, and their respective cost components, are presented in Table 5. 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 herd removal losses. On one French and one Swedish farm, negative removal costs were reported, suggesting an economic benefit following herd removal, 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 herd removal 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 herd removal 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 disorders, contributed only marginally to the total FC, whereas herd removal 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 disorder is presented in Figure 2 including any significant differences among 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 metritis were found highest on German farms compared to the other three countries P≤0.001.

Although the magnitude of FC for the four disorders varied among countries a Kruskal-Wallis test on the relative ranking on the individual farm of the four disorders by their FC estimates indicated that, for all countries, mastitis was the disorder 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.

Discussion

Our study estimated the farm specific FC of four common production disorders, mastitis, ketosis, lameness and metritis on European organic dairy farms. FC estimations of production disorders on organic dairy farms have not been estimated previously. Moreover, the method used in this study estimates the FC of multiple disorders by setting up a framework which makes it possible to make on-farm comparisons on the economic impact of the disorders. A large variation in FC estimates both among and within the studied countries is reported. This variation is provoked by the differences in disease incidence levels and by the variation in herd price levels.

The use of average technical input values to represent production losses, treatments and culling rates acts as a limitation in that respect, resulting in an underestimation of the actual herd variance. However, the aim of this study was to estimate the farm specific failure costs by using readily available farm data, which justified the assumption on average technical input parameters.

For the parameterisation of technical input values insights from studies based on data from conventional farms were used. Biological herds, however, may have different breeds and consequently have different herd milk production levels than conventional herds. To account for this breed aspect production losses were defined as a relative decrease in average herd production level. Meaning that low production herds had lower absolute milk production losses that high yielding farm, reflecting the current believe that production losses are higher in high yielding herds.

The herd removal behaviour of the farmers regarding the various production disorders was not recorded which could have led to an overestimation of the failure costs in cases were affected animals were immediately removed upon diagnosis, to prevent the occurrence of production losses and treatment costs. Such a situation can be attractive to the farmer when rearing costs are low, slaughter values are high and/or a low milk price is received. Occurrences of these conditions as experienced on some of the evaluated farms reflect a high economic opportunity for such an early cull strategy, provided that a replacement heifer is available directly after the herd removal of the affected cow. These situations should be accounted for in future costs estimations when individual follow-up data would be available.

A comparison of the incidence levels found in our study compared to a large set-up study on the incidence levels of multiple postpartum disorders in conventional herds in 10 EU countries found similar variations in incidence levels regarding mastitis, ketosis, lameness and metritis (Suthar et al., 2013). The average incidence levels in that study tended to be lower than the incidence levels reported in our study. Nevertheless, other studies reported incidence levels in organic systems to be comparable to incidence levels found in conventional systems (Hovi et al., 2003; Sutherland et al., 2013; van Wagenberg et al., 2017).

Health disorder 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 disorders which may over- or underestimate the true incidence levels (Bartlett et al., 2001; Richert et al., 2013; Richert et al., 2013). In our study, the incidence of a large proportion of production disorders 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; Čejna and Chládek (2005); Krogh et al. (2011)), or via an assessment made following a protocol, such as the Welfare Quality® assessment protocol for cattle. In our study the farmer's veterinarian was present to confirm incidence levels of the various production disorders to prevent reporting bias by the farmer. Input variables derived from official recordings could also be disputed. For example, in this study a cut off value of >1.5 during the first 100 DIM was used as introduced by Čejna and Chládek (2005) and evaluated by Krogh et al. (2011) as an effective herd level indicator although limited by sensitivity (0.63) and specificity (0.79). Meaning that our study should (with generally low prevalence levels) yield many more false positives than false negatives. The FPR is thus expected to overestimate the true prevalence. A comparison with prevalence studies performed in the EU, however, e.g. van der Drift et al., (2012) or Berge and Vertenten (2014) seems to confirm that our study may be underestimating rather than overestimating SCK prevalence. Moreover, the aforementioned studies used cows-sides test generally recognized as having a higher accuracy (keto-test and BHBA blood levels). The general believe is that herd with a lower milk production level have less cases of ketosis (Vanholder et al., 2015). The general lower production levels and different breeds used may lead to lower levels of SCK in organic dairy farms. Based on the aforementioned reasons and the rationalism method and face validity (Sørensen, 1990) we decided that FPR results were an appropriate indicator for SCK in this study.It should be noted that better indicators may become present over time e.g. routinely collected claw health data derived from claw trimmers recordings or BHBA levels in milk, urine or blood from dairy cows as an indicator for subclinical ketosis. At the moment these data were not routinely collected.

Furthermore, the availability of information among countries differs and may be more evolved, such as the use of Bulk tank SCC vs. individual reports on SCC. To omit 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 (Gohary et al., 2016; McArt et al., 2015). Conversion of these costs factors using the incidence 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. Recent estimates on the FC of metritis reported values of $171 to $262 per case under US conditions (Liang et al., 2017) which exceeds our own estimates. The study performed by Liang et al. included increased costs caused by secondary disorders (e.g. ketosis, mastitis). Metritis incidence in our study was reported by the farmer only and could not rely on any official recorded data. 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 among farms. The merit in our study thus lies in the fact that the FC estimates are farm specific whereas economic simulation models reflect only average farm situations. In practice this provides a transparent tool for farmers to explore their FC by using readily available farm information. Contrary to model studies, the variation within disorders (e.g. various pathogens may cause mastitis in various forms and severity) however, was not taken into account. FC estimations for each disorder were generalized as the available information lacked insights on the underlying aetiology. The value in such calculation lie in the fact that the outcomes serve as a warning mechanism to indicate the need for further exploration to define the exact cause and determine the most relevant treatment options.

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 disorder and thereby benefiting in the reduction of the FC of other disorders (McArt et al., 2015), based on the findings in our study, may in practice not hold for all disorders. 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., 2017, 2016). 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 adaptable to the individual farm circumstances and less time-consuming than simulation models (Cannas da Silva et al., 2006). 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, provided that farmers are able to detect and report each case of a disorder or veterinarians are involved in validation of the farm health data input. The tailored FC estimation method used in our study could be used to strengthen the farm advice provided by e.g. the veterinarian. The acceptance and potential possibilities for future application of on-farm calculation tools should therefore be the focus of new studies.

Conclusion

This study is the first to explore on-farm FC of four common production disorders on EU organic dairy farms. Using a structured method enabled a comparison of FC estimates on the individual farm for multiple production disorders. 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 among 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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Table 1 . Overview of evaluated categories of production disorders,their associated case definition, origin of the data source to determine incidence levels and cost elements affected by the disorder .

Production disorder	Case definition	Data source used in incidence estimation	Costs element(s) affected (see Figure 1)
Mastitis			
Clinical mastitis	Gross abnormalities in secreted milk (e.g. discoloration, clots, flakes and pus) and/or physical abnormalities of the udder: acute, diffuse swelling and warmth, pain and gangrene in severe cases, chronic local fibrosis and atrophy (Radostits et al., 2007).	Farm recordings	Milk production loss, treatment, herd removal
Subclinical mastitis	Diagnosed based on individual somatic cell count or based on bulk tank somatic cell count (Huijps et al., 2008; Halasa et al., 2009).	Milk records	Milk production loss
Ketosis			
Clinical ketosis	Cattle show wasting with decreased appetite, fall in body condition and milk production where some cows have short periods of bizarre neurological and behavioural abnormality (Radostits et al., 2007).	Farm recordings	Milk production loss, treatment labour, herd removal
Subclinical ketosis	Measured as a disturbed fat: protein ratio (FPR >1.5) in the milk during the first 100 days in milk (Duffield et al. 1997;, Čejna and Chládek, 2005).	Milk records	Milk production loss
Lameness			
Moderate lameness	Measured in moving animals, defined as imperfect temporal rhythm in stride creating a limp (Welfare Quality®, 2009).	Welfare Quality® assessment protocol on-farm assessment	Milk production loss, treatment, herd removal
Severe lameness	Measured in moving animals, defined as strong reluctance to bear weight on one limb, or more than one limb affected (Welfare Quality®, 2009).	Welfare Quality® assessment protocol on-farm assessment	Milk production loss, treatment, herd removal
Metritis			
Early metritis	Only clinical forms reported[1], occurs within 21 days postpartum 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).	Farm recordings	Treatment, herd removal
Late metritis	Only clinical forms reported[1], clinical late metritis is defined as the presence of a purulent uterine discharge detectable in the vagina 21 days or more postpartum or mucopurulent discharge detectable in the vagina after 26 days postpartum (Sheldon et al., 2009).	Farm recordings	Milk production loss, treatment, herd removal

[1] Detection of subclinical metritis is typically done by measuring polymorphonuclear neutrophils exceeding a predefined threshold value or through ultrasonography of the uterus (Kasimanickam et al., 2004; Lenz et al., 2007). Both methods are time consuming and require the expertise of an experienced veterinarian.

Table **2** Technical input parameters, derived from test-day records, herd health recordings or via a questionnaire responses of the farmer, indicated by 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)
Died 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 **3** Default technical input parameters related to the consequences of a disorder, derived from literature, experts' knowledge, authors' expertise or manufacturers' norm,.

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.* (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.* (2003)
Lameness classes		Green *et al.* (2002), Bicalho *et al.* (2008) and Bruijnis *et al.* (2010)
Non	0	
Moderate	3	
Severe	8	
Early metritis parity classes		Rajala and Gröhn (1998)
P1	0.28	
P2	0.26	
P3	0.84	
P4+	0.54	
Late metritis	0	
Milk withdrawal period antimicrobials (days)		
Mastitis	6	Manufacturers' norm
Ketosis	NA[2]	
Lameness	7	Manufacturers' norm
Early metritis	5	Manufacturers' norm
Late metritis	NA[2]	
Labour requirements (min / treatment / clinical case)		
Mastitis	45	Huijps *et al.* (2008), van Soest et al. (2016)
Ketosis	20	Experts' knowledge and authors' expertise
Lameness	70	Bruijnis *et al.* (2010)
Early metritis	30	Experts' knowledge and authors' expertise
Late metritis	15	Experts' knowledge and authors' expertise

[1] FPR = Fat / Protein ratio
[2] NA = Not applicable

Table **4** Economic input parameters reference values, percentage of dairy farmers that made a change in the reference value and the resulting range of adjusted values for DE (n=60), ES (n=21), FR (n=39) and SE (n=40).

Variable	Country	Reference value	Farmers adjusting reference value	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)[1]				
	DE	-	5%	637 (50; 1,000)
	ES	-	-	-
	FR	-	46%	1,434 (302; 4,642)
	SE	-	55%	527 (26; 2,258)
Bonuses missed (€/yr)[2]				
	DE	-	10%	555 (50; 1,617)
	ES	-	-	- (-; -)
	FR	-	10%	1,121 (616; 1,616)
	SE	-	75%	2,168 (-; 6,732)

[1] Penalties paid last year for having a too high cell count (€ per year)
[2] Bonuses missed for having a too high cell count during the last year (€ per year)

Table **5** Failure costs (FC) estimation for the four disorders (mastitis, ketosis, lameness and (endo)metritis) and the respective disorder 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)
Herd removal	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)
Herd removal	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)
Herd removal	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)
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)
Herd removal	13 (-1[2]; 84)	0 (0; 0)	2 (0; 23)	0.9 (0; 17)
Total FC 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 herd removal occur when revenues from cow sales are higher than costs of rearing new heifer for replacement, thus representing a benefit.

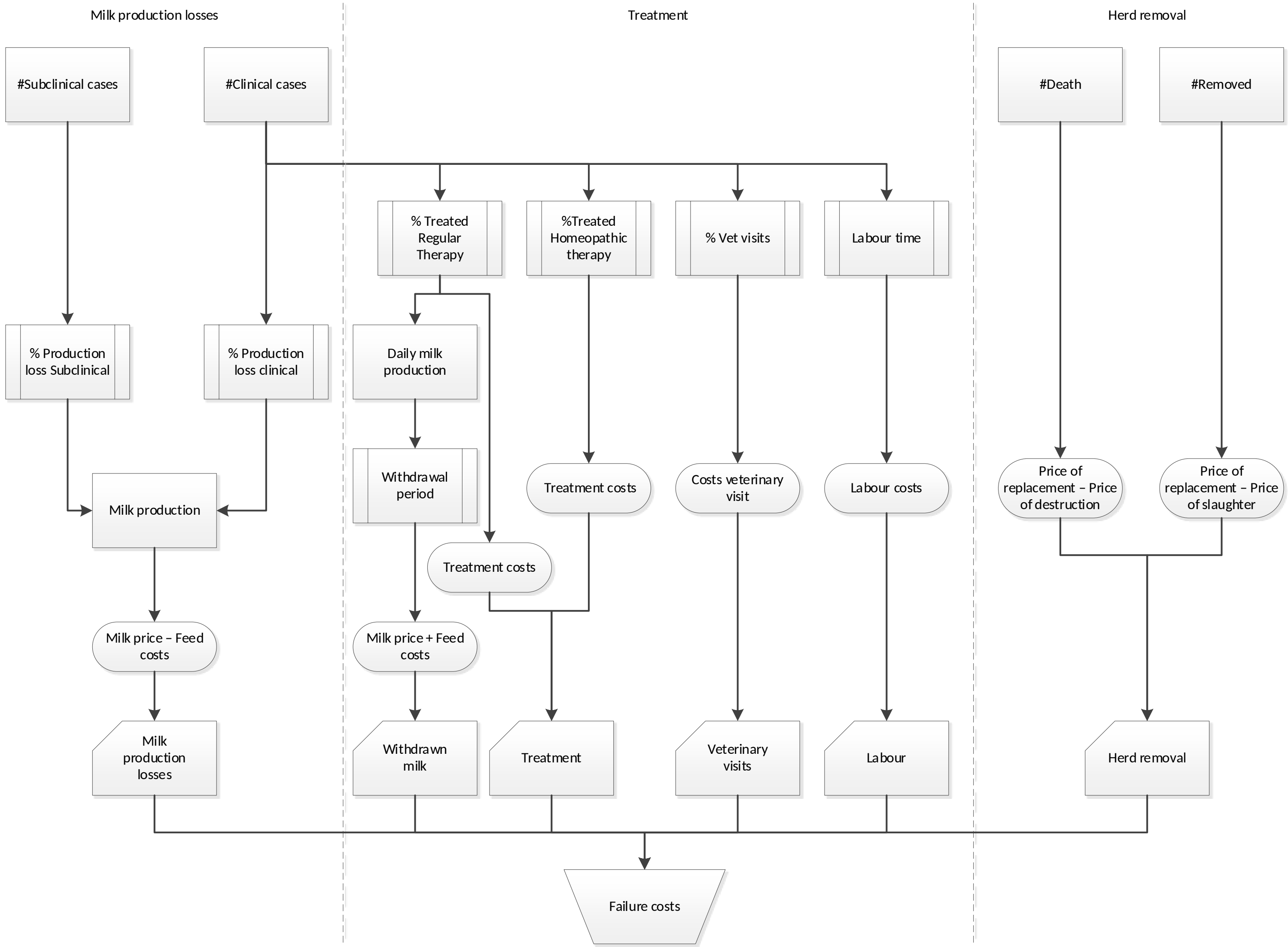

Figure **1** van Soest et al.

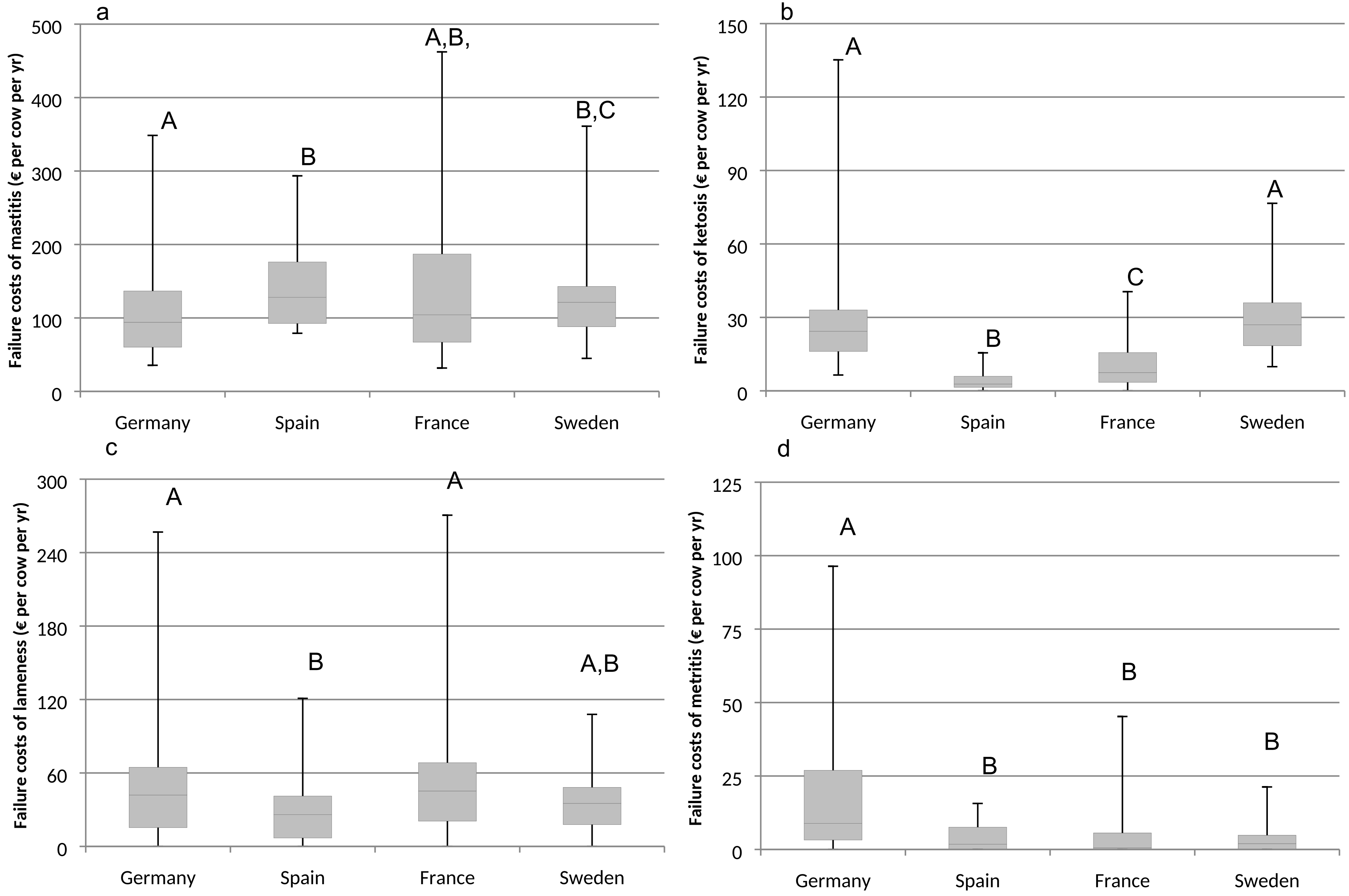

Figure **2** van Soest et al.

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 herd removal. Model input requires performance input (squares), consequential input (squares within squares) and economic input (rounds).

Figure **2**[a,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 indicates a significant difference at $P < 0.05$, following a non-parametric Kruskal-Wallis test.

Appendix I Costs calculations for individual disorders

Mastitis

Costs are presented on herd level in €/farm/yr, for an evaluation of average costs per dairy cow results need to be divided by the number of dairy cows on the farm (N_{cows})

Costs of milk production loss subclinical mastitis:

$$MPloss_{SCM} = [F_{SCC50} \times N_{cows} \times MP_{yr} \times PMPloss_{SCC50} + F_{SCC100} \times N_{cows} \times MP_{yr} \times PMPloss_{SCC100} + F_{SCC200} \times N_{cows} \times MP_{yr} \times PMPloss_{SCC200} + F_{SCC300} \times N_{cows} \times MP_{yr} \times PMPloss_{SCC300} + F_{SCC400} \times N_{cows} \times MP_{yr} \times PMPloss_{SCC400} + F_{SCC>400} \times N_{cows} \times MP_{yr} \times PMPloss_{SCC>400}] \times [P_{milk} - P_{feed}]$$

In which F is the fraction of dairy cows in the specific class, (SCC0-50, SCC50-100, SCC100-200,…SCC>400). N_{cows} is the number of dairy cows on the farm, MP_{yr} is the average milk production per cow per year (kg/cow/yr), $PMPloss_{SCC}$ is the percentage reduction in milk production for each respective SCC class, and P_{milk} and P_{feed} are the price of milk (€/kg milk) and feed (€/kg milk)

Costs of milk production loss clinical mastitis:

$$MPloss_{CM} = [N_{CM} \times MP_{yr} \times PMPloss_{CM}] \times [P_{milk} - P_{feed}]$$

In which N_{CM} is the number of cows with clinical mastitis (cases per yr) and $PMPloss_{CM}$ is the percentage reduction in milk production for each case of clinical mastitis

Costs of medication

$$Medication_{CM} = [N_{CMAB} + N_{CMNAB}] \times P_{medCM}$$

In which N_{CMAB} is the number of cows with CM treated with antibiotics N_{CMAB} is the number of cows with CM treated without antibiotics and P_{medCM} is the price of medication.

Costs of veterinary treatment

$$Vet_{CM} = N_{CM} \times F_{VetCM} \times P_{VetCM}$$

In which F_{VetCM} is the fraction of cows with CM which require veterinary visit and P_{vetCM} is the price of a veterinary visit.

Costs of discarded milk

$$DM_{CM} = N_{CMAB} \times MP_{day} \times [P_{milk} + P_{feed}] \times D_{DMCMdiscard}$$

In which MP_{day} is the average milk production per cow (kg milk/cow/day) and $D_{DMCMdiscard}$ is the withdrawal period in days.

Costs of alternative treatments

$$AltT_{CM} = N_{AltTCM} \times P_{AltTCM}$$

In which N_{AltTCM} is the number of cows with CM receiving alternative treatment and P_{AltTCM} the price of one full treatment.

Costs of labour

$$Labour_{CM} = N_{CM} \times [TrtTime_{CM}/60] \times P_{Labour}$$

In which $TrtTime_{CM}$ is the treatment time (minutes) a farmer has to spend on one case of CM and P_{labour} is the costs of labour (€/hr)

Costs of herd removal

$$Removal_{CM} = N_{culCM} \times [P_{rep} - P_{slv}] + N_{desCM} \times [P_{rep} + P_{slv}]$$

In which N_{culCM} is the number of cows voluntarily culled for mastitis reasons, N_{desCM} is the number of dairy cows that died on the farm and subsequently destructed as a consequence of mastitis, P_{rep} is the replacement value of an average dairy cow (€/cow) and P_{slv} is the slaughter value for an average dairy cow (€/cow).

Total Costs of mastitis

$$C_{mastitis} = MPloss_{SCM} + MPloss_{CM} + Medication_{CM} + Vet_{CM} + DM_{CM} + AltT_{CM} + Labour_{CM} + Removal_{CM}$$

Lameness

Costs are presented on herd level. Costs categories are the same as presented above for mastitis but now directed to lameness (indicated by L). Only deviating input variables are described in more detail.

Milk production loss lameness

$$MPloss_L = [N_{L1} \times MP_{yr} \times PMPloss_{L1} + N_{L2} \times MP_{yr} \times PMPloss_{L2} + N_{L3} \times MP_{yr} \times PMPloss_{L3}] \times [P_{milk} - P_{feed}]$$

In which N_{L1} is the number of cows with lameness category 1, N_{L2} is the number of cows with lameness category 2 and N_{L3} is the number of cows with lameness category 3.

Costs of discarded milk

$$DM_L = N_{LAB} \times MP_{day} \times [P_{milk} + P_{feed}] \times D_{DMLdiscard}$$

Costs of medication

$$Medication_L = [N_{LAB} + N_{LNAB}] \times P_{medL}$$

Costs of veterinarian

$$Vet_L = N_{L3} \times F_{VetL} \times P_{VetL}$$

Costs of alternative therapy

$$AltT_L = N_{AltTL} \times P_{AltTL}$$

Costs of labour

$$Labour_L = N_{L3} \times [TrtTime_L/60] \times P_{Labour}$$

Costs of herd removal

$$Removal_L = N_{cullL} \times [P_{rep} - P_{slv}] + N_{desL} \times [P_{rep} + P_{slv}]$$

Total Costs of lameness

$$C_{lameness} = MPloss_L + Medication_L + Vet_L + DM_L + AltT_L + Labour_L + Removal_L$$

Costs of ketosis

Costs are presented on herd level. Costs categories are the same as presented above for mastitis but now directed to ketosis (indicated by SCK for subclinical ketosis and by CK for clinical ketosis). Only deviating input variable are described in more detail.

Milk production loss subclinical ketosis

$$MPloss_{SCK} = N_{SCK} \times MP_{yr} \times PMPloss_{SCK} \times [P_{milk} - P_{feed}]$$

Milk production loss clinical ketosis

$$MPloss_{CK} = N_{CK} \times MP_{yr} \times PMPloss_{CK} \times [P_{milk} - P_{feed}]$$

Costs of discarded milk

$$DM_{CK} = N_{CKAB} \times MP_{day} \times [P_{milk} + P_{feed}] \times D_{DMCKdiscard}$$

Costs of medication

$$Medication_{CK} = [N_{CKAB} + N_{CKNAB}] \times P_{medCK}$$

Costs of alternative therapy

$$AltT_{CK} = N_{CK} \times 0.5 \times P_{AltTL}$$

Costs of veterinarian

$$Vet_{CK} = N_{CK} \times F_{VetCK} \times P_{VetCK}$$

Costs of labour

$$Labour_{CK} = N_{CK} \times [TrtTime_{CK}/60] \times P_{Labour}$$

Costs of herd removal

$$Removal_{CK} = N_{culCK} \times [P_{rep} - P_{slv}] + N_{desCK} \times [P_{rep} + P_{slv}]$$

Total Costs of ketosis

$$C_{ketosis} = MPloss_{SCK} + MPloss_{CK} + Medication_{CK} + Vet_{CK} + DM_{CK} + AltT_{CK} + Labour_{CK} + Removal_{CK}$$

Costs of metritis

Costs are presented on herd level. Costs categories are the same as presented above for mastitis but now directed to ketosis (indicated by EM for early metritis and by LM for late metritis). Only deviating input variables are described in more detail.

Milk production loss early metritis

$$MPloss_{EM} = [N_{EM} \times F_{P1} \times MP_{yr} \times MP_{corrP1} \times PMPloss_{EMP1}] + [N_{EM} \times F_{P2} \times MP_{yr} \times MP_{corrP2} \times PMPloss_{EMP2}] + [N_{EM} \times F_{P3} \times MP_{yr} \times MP_{corrP3} \times PMPloss_{EMP3}] + [N_{EM} \times F_{\geq P4} \times MP_{yr} \times MP_{corr \geq P4} \times PMPloss_{EM \geq P4}] \times [P_{milk} - P_{feed}]$$

In which F_{P1} is the fraction of dairy cows in parity 1, F_{P2} is the fraction of cows in parity 2, MP_{corrP1} is the correction factor for milk production for parity 1 cows, MP_{corrP2} is the correction factor for milk production for parity 2 cows

Milk production loss late metritis

$$MPloss_{LM} = N_{LM} \times MP_{yr} \times PMPloss_{LM} \times [P_{milk} - P_{feed}]$$

Costs of discarded milk

$$DM_{EMLM} = N_{EMLMAB} \times MP_{day} \times [P_{milk} + P_{feed}] \times D_{DMEMLMdiscard}$$

Costs of labour

$$Labour_{EMLM} = [N_{EM} \times [TrtTime_{EM}/60] \times P_{Labour}] + [N_{LM} \times [TrtTime_{LM}/60] \times P_{Labour}]$$

Costs of herd removal

$$Removal_{EMLM} = N_{culEMLM} \times [P_{rep} - P_{slv}] + N_{desEMLM} \times [P_{rep} + P_{slv}]$$

Costs of veterinarian

$$Vet_{EMLM} = N_{EMLM} \times F_{VetEMLM} \times P_{VetEMLM}$$

Costs of medication

$$Medication_{EMLM} = [N_{EMLMAB} + N_{EMLMNAB}] \times P_{medEMLM}$$

Costs of alternative therapy

$$AltT_{EMLM} = N_{EMLM} \times 0.5 \times P_{AltTEMLM}$$

Total Costs of ketosis

$$C_{metritis} = MPloss_{EM} + MPloss_{LM} + Medication_{EMLM} + Vet_{EMLM} + DM_{EMLM} + AltT_{EMLM} + Labour_{EMLM} + Removal_{EMLM}$$