Economic Potential of Selective Dry Cow Therapy in California

The balance between cost of mastitis and use of antibiotics in Californian dairy herds

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1. Abstract

Antibiotic resistance is a worldwide food safety and medical issue. One of the ways to combat the problem with resistance is by reducing the use. The dairy sector in California uses a lot of intramammary antibiotics to prevent and cure mastitis during the dry period. As a standard, all cows starting their dry period will be treated with antibiotics, the so-called blanket dry cow therapy. By implementing a new selective system, selective dry cow therapy (SDCT), antibiotic use can be reduced substantially, however mastitis incidence goes up. Mastitis remains a costly disease, in lost milk yield and treatment cost. In this study the optimal balance between mastitis and antibiotic cost is studied to evaluate the potential to promote SDCT in the state of California. Regression analysis is used to find a combination of variables that can predict the mastitis status of a cow after the dry period based on the udder health status before drying off. These predictive models were used to estimate mastitis incidence in an example herd. Linear programming was used to determine the amount of antibiotics to use giving the lowest overall costs for mastitis. The linear programming model provides the threshold to select a cow for antibiotics, giving the best balance between costs for mastitis and costs for antibiotics. In all cases SDCT is more cost beneficial than BDCT. So, antibiotics can be reduced during the dry period in large dairy herds in California while not compromising on farmer's wallets or their cattle.

2. Introduction

2.1 Background

A century ago Alexander Fleming accidentally discovered the antibiotic penicillin (Bennett & Chung, 2001). With this discovery Fleming changed the world as we knew it. A simple scratch in the garden was not lethal any longer. Infections in the medical and veterinary field could now effectively and easily be treated. Antibiotics are chemicals that kill or inhibit the growth of micro-organisms (Waksman, 1947). However, after Fleming discovered antibiotics he made a chilling prediction that soon came true: resistant bacteria (Rosenblatt-Farrell, 2009). A resistant bacterium is a micro-organism that is unaffected by antibiotics. This is developing into a huge problem, because infections with resistant microbes cannot be treated by antibiotics any longer. Antibiotic resistant bacteria are already causing thousands of deaths worldwide each year, and the number is rising (Alanis, 2005; Willyard, 2017). It is estimated that in the year 2050 annually 10 million deaths will be attributed to antibiotic resistance, which is equal to the amount of people dying of cancer yearly now (Kraker, et al., 2016; Tagliabue & Rappuoli, 2018).

Many scientist believe we can still turn the tide (Rosenblatt-Farrell, 2009). The best ways to combat the resistance problem are discovering new antibiotics and reducing the amount used today (Aidara-Kane et al., 2018). The food industry is a known contributor the antibiotic resistance, and the dairy sector is no exception (Alanis, 2005; Oliver et al., 2010). Amongst others, antibiotics are used to combat mastitis, which is an udder infection caused by bacteria (Scherpenzeel, et al., 2018). Mastitis is financially taxing, a farmer incurs treatment cost and milk losses (Gonçalves et al., 2018; Hogeveen et al., 2019). Two important distinctions can be made for the disease, clinical and subclinical mastitis. Clinical mastitis is a severe infection where cows show inflammation symptoms and can require direct veterinary assistance in order to survive, often this is the major cost associated with clinical mastitis. Subclinical mastitis is a milder infection that is characterized by milk production losses, which is the major cost here. These costs together can be very high and a burden on a dairy farm. Therefore, effective control of mastitis is important, and thus why farmers go to great lengths to ensure the health of the herd

Besides this being a veterinary issue, the use of antibiotics is also a food safety problem. Antibiotic residues in milk are controlled and monitored in every delivery of milk to the processing plant.

Administration of antibiotics during dry period does not result in antibiotics in the milk (Welsh et al., 2019) unless cows calf earlier than expected. At that moment, antibiotics may still be in the udder and thus the first milk that a cow produces is contaminated. Milk is a very important food all across the world and should not place consumers at risk with its practices (Henry et al., 2015). Multiple studies have shown antimicrobial resistance linked to milk and mastitis (Sasidharan et al., 2011; Turutoglu et al., 2006; Wang et al., 2015). If there is any incomplete pasteurization or contamination afterwards, antibiotic resistant microbes can reach consumers (Olsen et al., 2004). Furthermore, there is a trend where more consumers are drinking raw milk (Oliver et al., 2009; Verraes et al., 2015). In multiple countries, MRSA and other multiple resistant bacteria have been isolated from dairy cattle (Wang et al., 2015). Consumers that drink raw milk or consume raw cheese can become ill with an antibiotic resistance microbe and in the worst case they could spread the resistance through a hospital visit (Oliver et al., 2005; Straley et al., 2006). Antibiotic resistance can be spread via other routes as well, such as improper handwashing by the dairy workers or manure used as fertilizer (Udikovic-Kolic et al., 2014).

Many of the antibiotics are given during the dry period to avoid milk dumping due to antibiotic residues. Dairy cows calf almost every year, and before the expected calving date they are “dried off”. In many regions this process is done with the help of antibiotics to treat infection and limit new intramammary infections (IMI) during the dry period (Scherpenzeel et al., 2014). To ensure effective control of mastitis, blanket dry cow therapy (BDCT) has been advised and practiced for many years. This method involves administering antibiotics to all cows in the dry period (Scherpenzeel et al., 2014). It is estimated that annually 11 tons of medically relevant antibiotics are being used preventively in the udders of dairy cows, in the United States alone (Bonsaglia et al., 2017). Selective dry cow therapy (SDCT) is an alternative. With this approach, dairy cows are selected based on their risk for infection for administering antibiotics (Scherpenzeel et al, 2018). This lowers the total use of antibiotics by about 50% (Patel et al., 2017), and 85% in quarters with low risk for infection (Scherpenzeel et al., 2014). The risk of infection can be estimated by the somatic cell count (SCC) measured in the milk, making this a good selection criterium. The SCC is a measure of the cows’ immune system and thus indirectly udder health and infection (Sharma, Singh, & Bhadwal, 2011). The higher the SCC, the higher the influx of leukocytes in the udder, which is linked to a more severe inflammatory response to an infection. A cutoff value for selecting the cows can be based on several criteria, amongst which the SCC or somatic cell score (SCS) a normalized SCC value that is frequently used in the US.

2.2 Problem statement and objectives

In this study, Californian dairy herds are analyzed. California is responsible for 20% of US milk production and thus has a large part of the dairy market (Matthews, et al., 2016). When reducing antibiotics used in the dry period, infection rates can go up and more cows can get mastitis. This is why it is important to find a balance where the antibiotics are not reduced so far that the animal welfare is lost. This has been done in the Netherlands and the UK (Berry & Hillerton, 2002; Scherpenzeel et al., 2018), however the situation in California is different. Therefore, the results for the Netherlands and the UK cannot directly be converted to California. So, while an optimization model will be used that was built for Dutch dairy herds it must be adapted to suit the Californian situation. The herds are much larger, often more than 10-fold the Dutch average. Labor cost are different than in the Netherlands, as hired help is used more often (Howitt, et al., 2014). The different circumstances thus provide a different chance of viability for SDCT. The economics is one side of the coin, but the infection rate is another, this brings more costs and problems for farmers too. The key is to find the balance and give farmers an economic incentive to switch from BDCT to SDCT. Mastitis is very costly and making a switch away from the long-held tradition that works well, is not an easy choice. The economics behind the choice, should make it easier.

The main objective of this study will be at what point is SDCT economically equal or more beneficial than BDCT in large dairy herds in California. The aim behind this, is to give farmers an economic incentive to reduce antibiotics. Three questions are asked to fulfil the main objective. Firstly, can we predict infection rate after the dry period by using the SCS of the last test day before drying off? Secondly, what are the costs associated with mastitis in an average Californian herd? Thirdly, how can the cost of SDCT be optimized? These three questions will provide the tools to answer the main question. The end result will be an economically optimal balance for when to use antibiotics in dairy udders, to thus help combat the antibiotic and food safety issue.

3. Materials and methods

3.1 Scope

When applying SDCT, it is important to have a good selection criterium. SCC can be used as selection criterium (Scherpenzeel et al., 2018). When a low threshold is used, many cows are treated with antibiotics unnecessarily, but when a high threshold is used, some cows may not be treated while they have an infection, leading to mastitis and associated losses in the next lactation. Determining the SCC selection level which corresponds with the highest profit for a dairy farm using SDCT is an optimization problem which can be solved by using linear programming. This is a method that optimizes a linear objective function in a set of given constraints (Scherpenzeel et al., 2018). A linear programming model for optimizing SCC thresholds for SDCT in The Netherlands exists already (Scherpenzeel et al., 2018). This is adapted for California, local data for SCS before the dry period is fitted to a function via a regression analysis, which predicts mastitis chance in early lactation after the dry period. This infection chance then serves as input for the adapted optimization model.

Since all the farms in the dataset practice BDCT, the regression analysis only provided results for the situation that cows are treated at drying off. To optimize the use of dry cow treatment (DCT) without antibiotics in a SDCT situation, it is also necessary to have the probability of cows getting mastitis when no antibiotics are given at drying off. Therefore, a penalty to the chance of mastitis was added for the situation that a cow is not treated with antibiotics. Overall, the approach to get insight in the probabilities of cows to get mastitis in after calving when treated with or without antibiotics is explained below. The UC Davis has kindly provided dairy herd improvement (DHI) data that they have collected over the past ten years (dataset 1). Furthermore, a selection of farms has supplied their detailed data, including clinical mastitis reports (dataset 2). These data sets form the basis of the infection rate analysis.

The set up follows the three questions asked in the introduction:

1. Can infection rate be predicted after the dry period with the SCS of the test day at drying off?
2. What are the costs associated with mastitis in an average Californian herd?
3. How can the cost of SDCT be optimized?

The data is first prepared for the regression analysis, which will answer the first question asked in the introduction. The predicted values of the regression for both clinical and subclinical mastitis become input for the linear programming model alongside the California specific costs answered by the second question. There is no data available for DCT without antibiotics infection rates, so a penalty on infection rate will be used to make a predicted line for drying off with no antibiotics. The linear programming model will optimize the cost of SDCT, three different example herds are used to simulate different realities and a sensitivity analysis is done as well. Finally, the point can be defined where SDCT it is more economically beneficial than BDCT, thus answering the main objective.

3.2 Data set preparation

Firstly, the data was cleaned to remove incomplete data. The original collected data provided SCS, not SCC, thus the SCS was used. This is a transformation to normalize SCC as follows:

$$SCS = \log_2\left(\frac{SCC}{100000}\right) + 3$$

Any data that was transformed to SCC was normalized back into SCS using this formula.

Following this, outliers and impossible data points were removed. Cows with negative SCS or negative days in milk. For the subclinical infection rate based on dataset 1, the first test day after the dry period was used for the regression. This first testing day was used instead of later test days to make the time gap before and after the dry period as small as possible. During the data preparation cows under 3 days in milk on the first test day were removed, as this milk is transition milk (colostrum). When cleaning the data set there was not a maximum, amount of days in milk since the start of the new lactation, defined to remove cows from the dataset for subclinical mastitis. For clinical mastitis based on dataset 2 the findings were not limited to test days, so a maximum of 90 days in milk was set to keep the findings in the early lactation were the mastitis could still be correlated to the dry period. A new case of mastitis was defined by 14 days in between two findings in a single cow during a lactation. The definition for primiparous cows was set as cows who have had only one dry period, so the last test day before drying off is during the first lactation and the first test day which determines clinical mastitis is in the second lactation.

The data was also analyzed to find average herd size and define the SCS categories to use in the regression analysis. In total 96 SCS categories were defined starting with 0.1 leading to 9.6 with increments of 0.1.

In California it is common practice to insert an internal teat sealant for all cows, so when no antibiotics are given it is still referred to as DCT.

3.3 Regression analysis

The first question can be answered with the regression analysis: Can infection rate be predicted after the dry period with the SCS of the last test day before drying off? To test this a logistic regression analysis was used. The DHI data, dataset 1, was used to predict the probability of subclinical mastitis, defined as a SCS of 4 or higher, as a function of the SCS in the last milking before drying off. Dataset 1 contains over 340 thousand cows and 424 farms.

When using the farm management data, dataset 2, the probability of clinical mastitis a notice of finding mastitis had to be written in the digital management system of a dairy. Six farms submitted their detailed data for the clinical infection rate analysis. The higher SCS categories contained very few cows, so it was decided that from SCS 7 onwards the categories would be grouped for clinical mastitis.

The logistic regression analyses were performed in R (R Core Team, 2019). Generalized linear models were used with a logit link. The variables that were chosen based on a likelihood ratio test, expertise, and amount of complexity the optimization model could handle. The size of the dataset meant that many variables would have a small P value in the likelihood ratio test. This is why the expertise and the complexity were also used as filters for selecting variables.

Following the logistic regression analyses, the performance of the regression models was evaluated with a receiver operating characteristics (ROC) curve. The ROC curve provides an illustration between sensitivity and specificity performance of a model (Fan, et al., 2006). ROCs can be compared with the area under the curve (AUC). It measures the capability of the logistic regression model to distinguish between cows with mastitis or without mastitis (Flach, 2016). An AUC of 0.5 is similar to flipping a coin, in 50% of the times the regression analysis was correct if a cow has mastitis or not.

3.4 Predicted values

All the farms were used in calculating the infection chance that was later used to predict illness in the optimization model. The predicted amount of cows with mastitis per SCS category was extracted from the data set using R. Primiparous and multiparous cow data was extracted separately. This was then converted to percentages to have predicted infection chance. Subsequently, a function was fitted to the subclinical mastitis dataset 1 points by using linear regression to find the best fit. For clinical mastitis all the SCS categories above 7 the same predicted infection chance would be used.

3.5 Cost calculation

The second question, what are the cost associated with mastitis, was answering by calculating the cost of mastitis with California specific inputs. The total cost of mastitis associated with calving (TMC) is the sum of total cost of mastitis per cow per SCS category, multiplied by the number of cows per SCS category. The total cost can be divided between subclinical (subclinical mastitis cost; SCMC) clinical mastitis (clinical mastitis cost; CMC), and dry cow therapy (cost dry cow therapy; CDCT):

$$TMC = CMC + SCMC + CDCT$$

The cost of clinical mastitis was calculated using an existing calculation tool (Huijps et al., 2008) with California specific inputs. The tool automatically calculates the cost of clinical mastitis after the inputs are entered, which is why there is no formula.

Subclinical mastitis cost is the sum of the milk production losses, calculated according to the formula below (Scherpenzeel et al., 2018):

$$SCMC = milk\ price \times milk\ production\ loss \times length\ of\ loss$$

In California it is common practice to insert an internal teat sealant for all cows, so when no antibiotics are given it is still referred to as DCT. The DCT cost of a cow that does not receive antibiotics is the cost to administer a teat sealant. While the cost to dry a cow with antibiotics also includes antibiotic tube cost and an extra minute per cow of labor. Below in the formula cost for DCT with antibiotics (a=1) is shown:

$$CDCT_{a=1} = (Antibiotic\ tube \times 4 + labour\ cost) + (teat\ sealant \times 4 + labour\ cost)$$

The cost without antibiotics can be seen below in the formula for cost of DCT (a=2):

$$CDCT_{a=2} = teat\ sealant \times 4 + labour\ cost$$

The cost inputs specific to California were obtained from experts that work in the field on a daily basis.

3.6 Example herds

To simulate the situation in California an example herd has been built, based on the average distribution of SCC in dataset 1. Two other herds were built, based on two specific farms in the data, one with a low average SCC , and one with a high average SCC. The low SCC example herd reflects the 25th percentile of all bulk tank SCC in dairy herds in California. The high BTSCC example herd matches the 75th percentile. These herds were included to show different scenarios. These example herds help answer the third question of how to optimize cost for SDCT, it provides alternative farms each where a different optimal point could be reached.

3.7 Linear programming

To optimize the cost of dry cow therapy, linear programming was used. This answers the third question asked in the introduction: how can the cost of SDCT be optimized. The objective was to minimize the overall cost, while the linear programming model could change if and how many cows would be dried off with antibiotics for each SCS category.

The objective function is given below, where TMC is total cost of mastitis associated with calving, which is to be minimized. There are p for parities, where 1 is primiparous and 2 is multiparous.

c’s for the SCS categories, where 1 is SCS 0.1 and 96 is SCS 9.6, and a is for the antibiotic status, where 1 is antibiotics, and 2 is no antibiotics. CDCT is cost of DCT.

$$\text{Min } TMC = \sum_{p=1,2}^{2} \sum_{c=1-96}^{96} \sum_{a=1,2}^{2} CDCT_{p,c,a} + SCMC_{p,c,a} + CMC_{p,c,a}$$

There was one system constraint: the number of cows allocated per category cannot be greater than the number of cows in each category. Furthermore, the amount of antibiotics could be restricted for the overall herd. Below the restriction for one SCS category and one parity example herd is shown.

The number of cows in a category should not be larger than the cows that can be dried off in category one. Ncows is number of cows the model could assign. C is for the SCS categories, where 1 is SCS 0.1, here an example category, the constraint was repeated 96 times for each category. Dcows are the amount of cows to be dried off per category. A is for the antibiotic status, where 1 is antibiotics, and 2 is no antibiotics.

$$Ncows_{c=1} \leq Dcows_{C=1}$$

$$Ncows_{c=1} = Ncows_{c=1,a=1} + Ncows_{c=1,a=2}$$

As mentioned above, the antibiotic amount could be restricted by total percentage antibiotics allowed. Where 100% antibiotics is a BDCT herd and everything below is a SDCT herd. This was done at 10% increments to see the effect of percentage antibiotics allowed on optimal cost. The constraint is thus dependent on the input filled in for the antibiotic percentage. P is for parity, where 1 is primiparous and 2 is multiparous. C is for the SCS categories, where 1 is SCS 0.1 and 96 is SCS 9.6. Ncows is number of cows the model could assign. A is for the antibiotic status, where 1 is antibiotics, and 2 is no antibiotics. AB is the percentage of antibiotics allowed in the herd.

$$\sum_{p=1,2}^{2} \sum_{c=1-96}^{96} Ncows_{p,c,a=1} = Ncows_{p,c,a} \times AB$$

The model would select for each category how many cows would receive antibiotics, whilst keeping the cost as low as possible and meet the set percentage of antibiotics. This model was based on a similar method by Scherpenzeel et al. for Dutch dairies (Scherpenzeel et al., 2018). However, this model was split into 3 parts, a model for each different examples herds and each of these models was subdivided into primiparous and multiparous, and these both contained 96 SCS categories. In total 6 linear programming models were separately optimizable.

3.8 Parameterization

Incidence rates, infection rate and mastitis probability all refer to the percentage of cows that had mastitis after the dry period for a specific SCS category on the last test day before drying off. This percentage only refers to early lactation, the first test period for subclinical mastitis and up to 90 days after calving for clinical mastitis. This was done to reduce the chance that at a certain point, mastitis could have arisen in the lactating period which is unrelated to the SCS before the dry period. This research only focuses on the dry period. No antibiotics DCT infection rate was based on no treatment during the dry period, but it is common practice in California to insert an internal teat sealant as protective measure at SDCT dairies.

In the optimization model a 1000 dairy cattle herd is used. The replacement percentage was set at 35%, these were the cows to be culled each year. The number of cows that were to be replaced and thus not dried off was set at 85%, some cows could have been dried off and culled later on, this accounts for the remaining 15%. The percentages were applied to the herd leading to yearly 350 primiparous cows to be dried off and 351 multiparous cows to be dried off. The total amount of lactating cows in the herd that was to be dried off came to 701. The number of cows per SCS category was defined by the percentage of cows in the example herds. However, total cost calculated uses the Californian average herd size.

The dairy herd improvement data from the Californian data contains only BDCT farms. This is the most common practice in the USA. This means that the results of the regression analyses only provided the probability of mastitis in relation with SCS , but in order to compare cost, also probability SDCT data was required (Bonsaglia et al., 2017). To achieve this, a type of penalty was decided upon to simulate the no antibiotic at dry off data. From literature it was deduced that dairies using BDCT after the dry period has approximately 5% incidence of mastitis in quarters, while no treatment ranged between 7.8% and 18% (Berry & Hillerton, 2002; Rindsig, et al., 1978; Vanhoudt et al., 2018). On average this equals to a relative 62% increase from when the cows do receive antibiotics. For each antibiotic receiving SCS category, a different infection rate was calculated with the predicted values for no antibiotics DCT.

3.9 Sensitivity analysis

Finally, a sensitivity analysis was done on the optimization model to assess its sensitivity to variation of the input variables and completely answer the third question posed in the introduction. The price of milk and cost of antibiotics were major influencers on the final total cost. These were altered to reflect different market scenarios of the future. In the table 7 the changes and corresponding final cost per cow can be seen

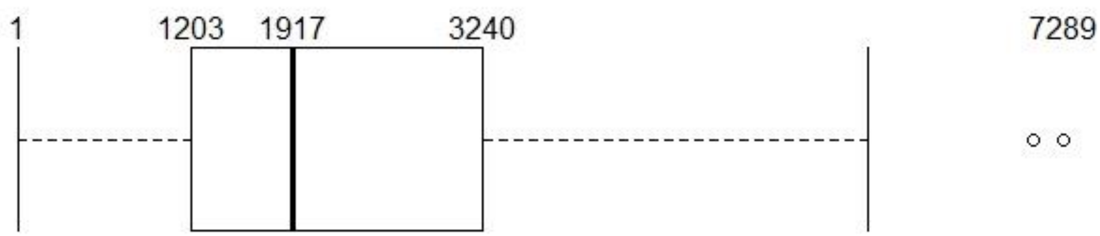
The DCT without antibiotics penalty was also altered. This was done because the penalty is expert based and it could be slightly different in the Californian situation or fluctuate per farm. The original penalty is 62% relative to when antibiotics are used in the DCT. This was changed to simulate alternative situations and differences amongst dairies. Finally, a break-even analysis was done to discover how much more infection chance cows that did not receive antibiotics should have to have equal cost as cows that receive antibiotics.

4. Results

4.1. Data set preparation

The data set preparation was the first step of the materials and methods. The average size of a herd in the data was found to be 2440 cows per dairy, a more detailed overview is given below in boxplot format, in figure 1.

Figure 1. Boxplot of cows per dairy in California. The first line is the minimum amount. The box consists of first the quarter percentile, then the median and then the third quarter percentile. The last line is the maximums along with two outliners.



4.2. Regression analysis

In the table below the P values are depicted for the subclinical mastitis logistic regression model, showing the statistical significance of the SCS before drying off and parity. For this reason, in the linear programming optimization model, the cows are split between primiparous and multiparous cows.

Table 1. Summary of logistic regression model where subclinical mastitis in the first test day after lactation is predicted by SCS and parity. Here the coefficients for primiparous cows are shown

Deviance Residuals

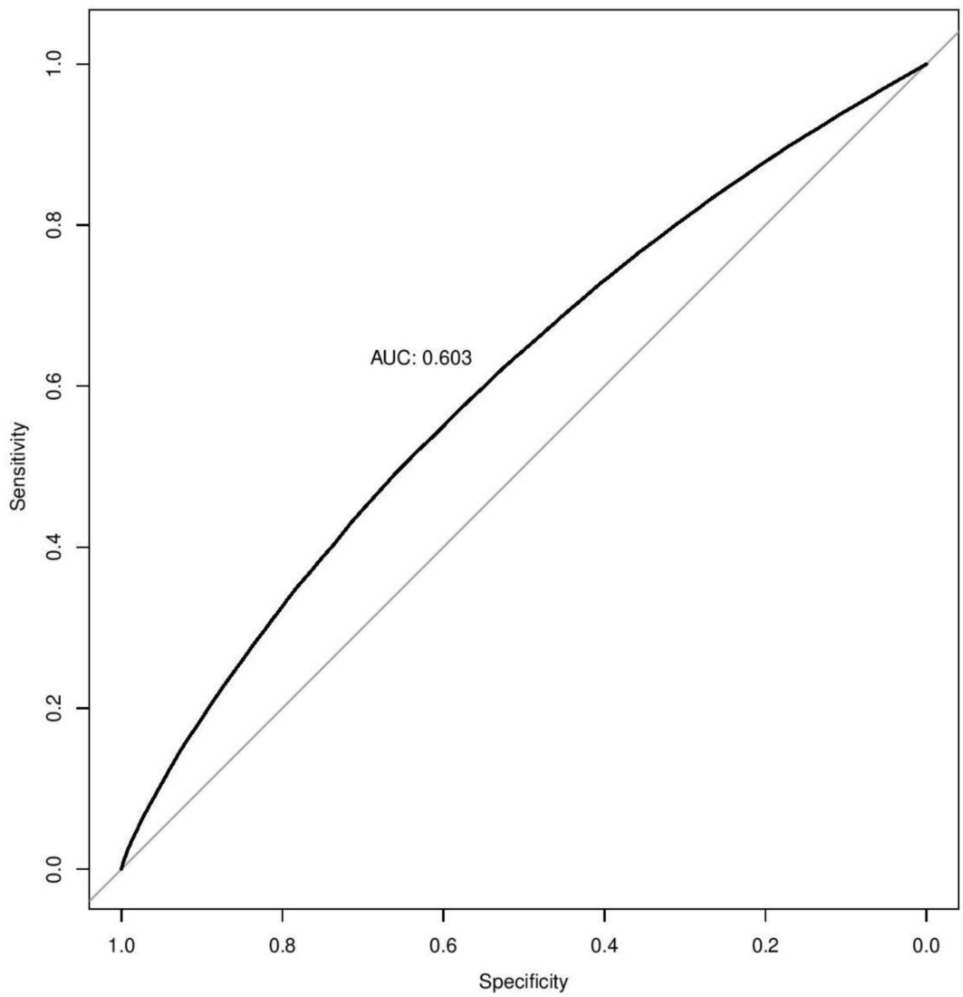
Min	*1Q*	*Median*	*3Q*	*Max*
-1.0689	-0.6571	-0.5652	-0.4664	2.1534

Coefficients

	Estimate	*Std. Error*	*Z value*	*Pr*
Intercept	-1.90168	0.1147	-165.80	<2e-16
Parity (prim)	-0.33036	0.00969	-34.09	<2e-16
SCS	0.17092	0.00284	60.19	<2e-16

The AUC for the subclinical mastitis logistic regression model is 0.603, which is above the 0.5 coin flip chance rate. In figure 2 the ROC curve with the AUC is depicted.

Figure 2. ROC curve of DHI data subclinical logistic regression model with AUC. The grey line represents an AUC of 0.5. The model has an AUC of 0.603.



This answers question 1 posed in the introduction: Can infection rate be predicted after the dry period with the SCS of the test day at drying off? The model shows that a higher SCS on the last test day before drying off equals a larger chance of subclinical mastitis after the dry period. So, SCS can be used to predict infection rate.

4.3. Predicted values

As described in paragraph 4.2, the probability of subclinical mastitis after calving in relation with the SCS in the last test day before drying off was assessed using linear regression. From the results formulas could be derived that provide the probability of subclinical mastitis in relation to the SCS before drying off. Formulas were derived for primiparous as well as multiparous:

$$Percentage\ subclinical\ mastitis\ primiparous = (1.9046 \times SCS) + 10$$

$$Percentage\ subclinicalmastitis\ multiparous = (3.9054 \times SCS) + 9.194$$

The regression formulas represent the probability of occurrence of subclinical mastitis as a function of the . These predicted values could be used as inputs for the optimization model.

For each SCS category, the infection probability was increased with a relative 62% DCT without antibiotics. The resulting probabilities of subclinical mastitis in relation to SCS before drying off are provided in figures 3 and 4. The infection rate was thus used as a base line infection rate and later in the optimization model

Figure 3. The subclinical mastitis infection rate of primiparous cows for DCT with antibiotics (1), and for DCT without antibiotics (2). Y axis is the percentage subclinical mastitis cases for primiparous cows, with X axis is each SCS category. Antibiotics (1) is depicted in blue with a solid line, and no antibiotics (2) is depicted in orange with a dashed line.

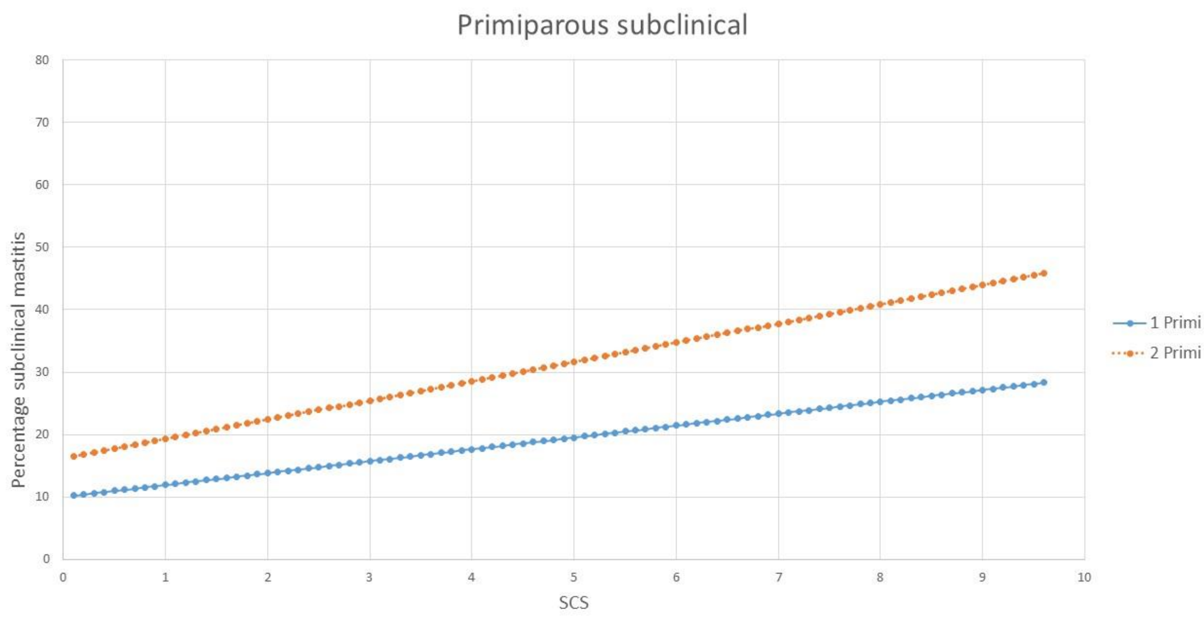
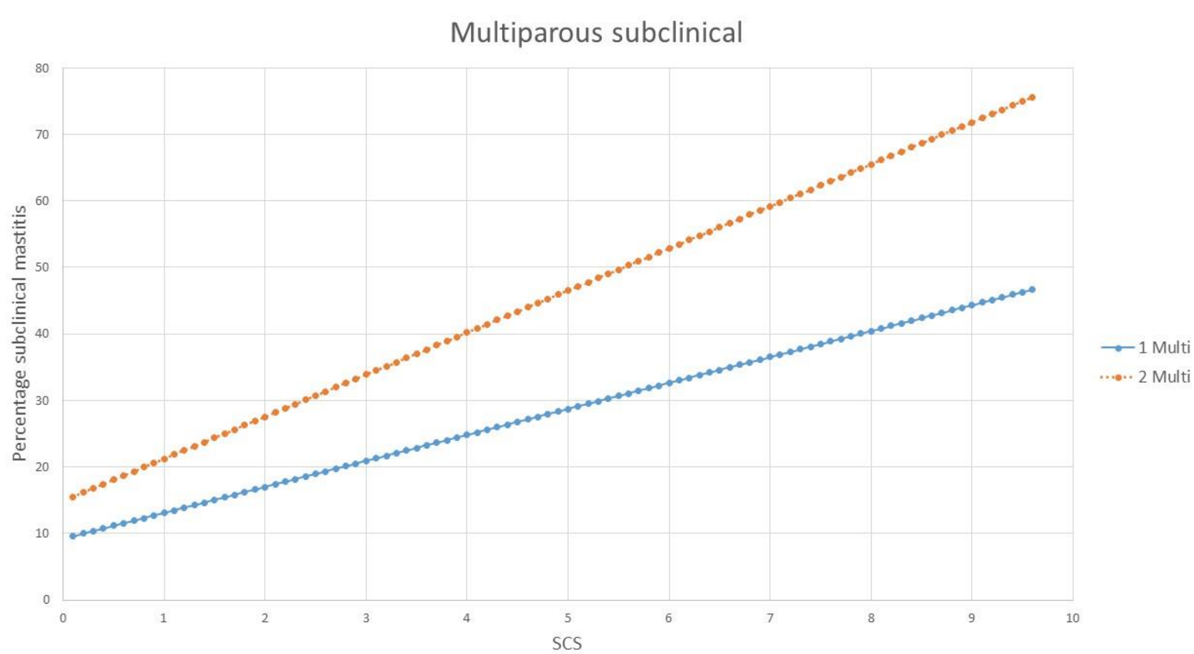


Figure 4. The subclinical mastitis infection rate of multiparous cows for DCT with antibiotics (1), and for DCT without antibiotics (2). Y axis is the percentage subclinical mastitis cases for multiparous cows, with X axis is each SCS category. Antibiotics (1) is depicted in blue with a solid line, and no antibiotics (2) is depicted in orange with a dashed line.



Similarly, the predicted infection probability for clinical mastitis in relation to the SCS at the last test day before drying off are plotted in figure 5 and figure 6, for primiparous and multiparous respectively. Also here the DCT without antibiotics literature based penalty of 62% was used. The SCS categories of 7 and above were grouped with as consequence that the predicted value only goes to 7. In the linear programming model, the mastitis incidence rate corresponding with SCS 7 is used for all categories from the threshold SCS 7 category onwards.

Figure 5. The clinical mastitis infection rate of primiparous cows for DCT with antibiotics (1), and for DCT without antibiotics (2). The DCT no antibiotics infection chance is a relative 62% higher than DCT with antibiotics. Y axis is the percentage subclinical mastitis cases for primiparous cows, with X axis is each SCS category. Antibiotics received at drying off (1) is depicted in blue, and no antibiotics received (2) is green.

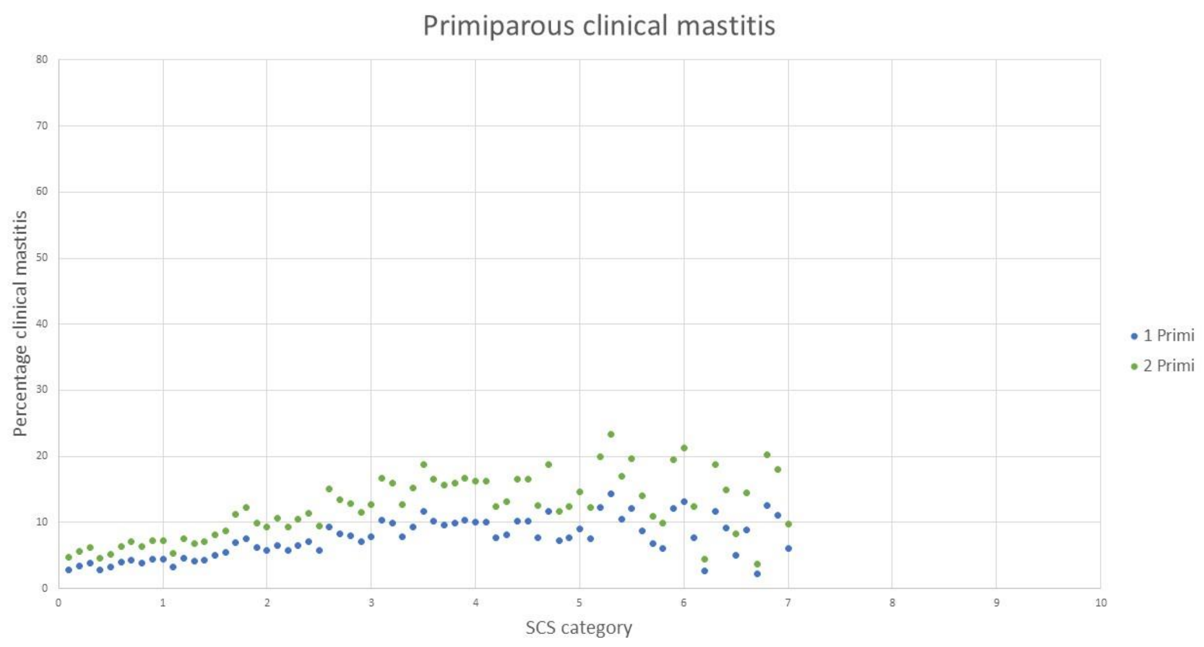
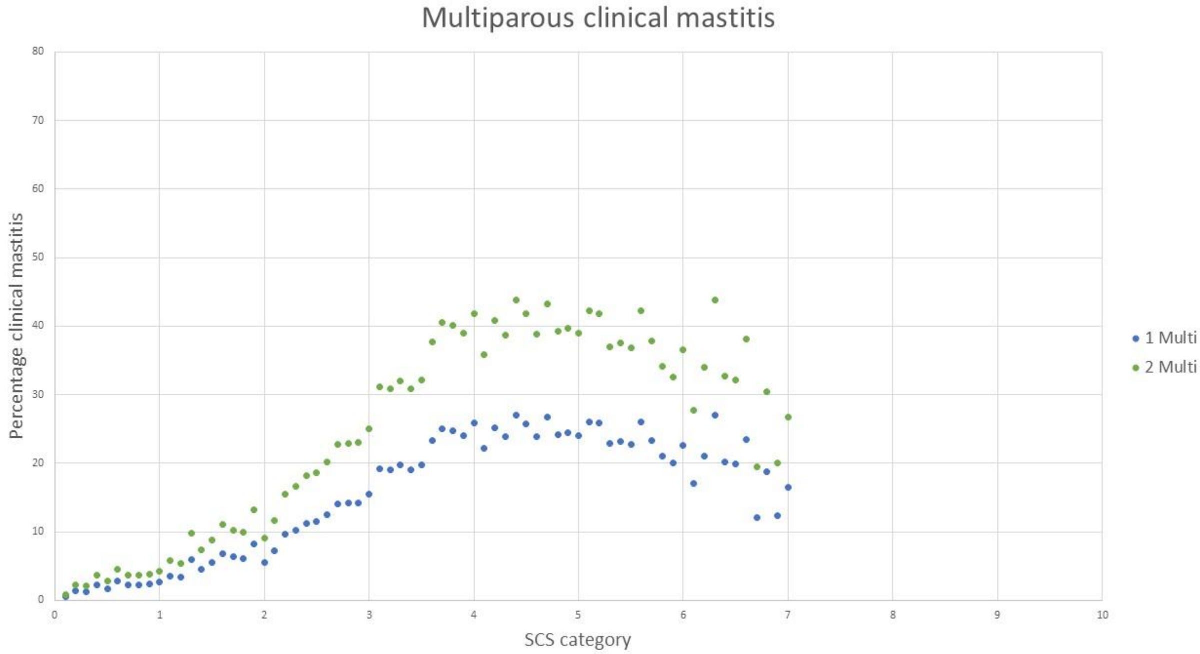


Figure 6. The clinical mastitis infection rate of multiparous cows for DCT with antibiotics (1), and for DCT without antibiotics (2). The DCT no antibiotics infection chance is a relative 62% higher than DCT with antibiotics. Y axis is the percentage subclinical mastitis cases for multiparous cows, with X axis is each SCS category. Antibiotics received at drying off (1) is depicted in blue, and no antibiotics received (2) is green.



4.4. Cost calculation

The total cost of one clinical case was estimated to be 218 dollars on average using the DHI data in dataset 1 and the specific costs found in table 2. The analysis was done using the economic tool described earlier (Huijps et al., 2008), which calculated the cost of a clinical case after inputting the California specific inputs. This answers the second question of the introduction: What are the costs associated with mastitis in an average Californian herd?

Table 2. Cost input for mastitis cost in California in United States dollars (expert based)

Item	*Cost*
Milk price	0.40 $/kg milk
Feed cost	0.28 $/kg milk
Labor cost	12 $/hour
Average replacement cost	1300 $/cow
Average destruction cost	50 $/cow

Slaughter price	700 $/cow
Cost of one antibiotic tube	3 $/quarter
Cost of one teat sealant	2 $/quarter

4.5. Example herds

The distributions of SCS before drying off and the probability of subclinical and clinical mastitis after calving for all three example herds are provided in table 3 (primiparous cows) and table 4 (multiparous cows). These tables form the basis for the optimization model and can be used in answering the last sub question: How can the cost of SDCT be optimized? Each example herd shows a different type of farm, with each its own optimal point.

Table 3. Primiparous distribution and corresponding clinical and subclinical incidence rate in dairy herds of 1000 dairy cattle. Three example herds can be seen, labeled for their BTSCC. Where low is a BTSCC of 111000 and high is a bulk tank of 217000, average sits in between with 155000. The incidence rates were determined with the above described regression methods. The infection rate of cows that received at antibiotics at drying off are in the column "Antibiotics" (1). Here the DCT with no antibiotics base penalty of 62% is used to fill the columns "No antibiotics" (2). This is a small excerpt of a larger table found in the appendix, table A-1.

SCS	*Average Primi-parous*	*Low Primi-parous*	*High Primi-parous*	*Clinical mastitis Antibiotics (1)*	*Clinical mastitis No antibiotics (2)*	*Subclinical mastitis Antibiotics (1)*	*Subclinical mastitis No antibiotics (2)*
0.1	4 Cow(s)	72 Cow(s)	2 Cow(s)	2.89 %	4.68 %	10.19 %	16.51 %
0.5	6 Cow(s)	6 Cow(s)	0 Cow(s)	3.19 %	5.17 %	10.95 %	17.74 %
1.0	5 Cow(s)	7 Cow(s)	5 Cow(s)	4.47 %	7.24 %	11.91 %	19.29 %
1.5	5 Cow(s)	4 Cow(s)	9 Cow(s)	4.98 %	8.07 %	12.86 %	20.83 %
2.0	8 Cow(s)	9 Cow(s)	10 Cow(s)	5.72 %	9.26 %	13.81 %	22.37 %

2.5	9 Cow(s)	9 Cow(s)	9 Cow(s)	5.83 %	9.45 %	14.76 %	23.91 %
3.0	7 Cow(s)	3 Cow(s)	14 Cow(s)	7.80 %	12.64 %	15.71 %	25.46 %
3.5	5 Cow(s)	4 Cow(s)	9 Cow(s)	11.62 %	18.83 %	16.67 %	27.00 %
4.0	4 Cow(s)	1 Cow(s)	4 Cow(s)	10.04 %	16.27 %	17.62 %	28.54 %
4.5	2 Cow(s)	1 Cow(s)	4 Cow(s)	10.19 %	16.50 %	18.57 %	30.09 %
5.0	2 Cow(s)	1 Cow(s)	3 Cow(s)	9.02 %	14.61 %	19.52 %	31.63 %
5.5	1 Cow(s)	0 Cow(s)	1 Cow(s)	12.09 %	19.58 %	20.48 %	33.17 %
6.0	1 Cow(s)	1 Cow(s)	0 Cow(s)	13.14 %	21.28 %	21.43 %	34.71 %
6.5	0 Cow(s)	1 Cow(s)	0 Cow(s)	5.08 %	8.24 %	22.38 %	36.26 %
7.0	0 Cow(s)	0 Cow(s)	2 Cow(s)	6.06 %	9.81 %	23.33 %	37.80 %
7.5	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	24.29 %	39.34 %
8.0	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	25.24 %	40.88 %
8.5	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	26.19 %	42.43 %
9.0	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	27.14 %	43.97 %
9.5	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	28.09 %	45.51 %

Table 4. Multiparous distribution and corresponding clinical and subclinical incidence rate in dairy herds of 1000 dairy cattle. Three example herds can be seen, labeled for their BTSCC. Where low is a BTSCC of 111000 and high is a bulk tank of 217000, average sits in between with 155000. The incidence rates were determined with the above described regression methods. The infection rate of cows that received at antibiotics at drying off are in the column "Antibiotics" (1). Here the DCT with no antibiotics base penalty of 62% is used to fill the columns "No antibiotics" (2). This is a small excerpt of a larger table found in the appendix, table A-2.

SCS	*Average Multi-parous*	*Low Multi-parous*	*High Multi-parous*	*Clinical mastitis Antibiotics (1)*	*Clinical mastitis No antibiotics (2)*	*Subclinical mastitis Antibiotics (1)*	*Subclinical mastitis No antibiotics (2)*

0.1	8 Cow(s)	10 Cow(s)	0 Cow(s)	0.52 %	0.84 %	9.58 %	15.53 %
0.5	2 Cow(s)	4 Cow(s)	0 Cow(s)	1.74 %	2.82 %	11.15 %	18.06 %
1.0	2 Cow(s)	1 Cow(s)	0 Cow(s)	2.66 %	4.31 %	13.10 %	21.22 %
1.5	3 Cow(s)	4 Cow(s)	3 Cow(s)	5.46 %	8.85 %	15.05 %	24.38 %
2.0	6 Cow(s)	6 Cow(s)	4 Cow(s)	5.59 %	9.05 %	17.00 %	27.55 %
2.5	9 Cow(s)	8 Cow(s)	9 Cow(s)	11.53 %	18.68 %	18.96 %	30.71 %
3.0	10 Cow(s)	11 Cow(s)	12 Cow(s)	15.48 %	25.08 %	20.91 %	33.87 %
3.5	9 Cow(s)	10 Cow(s)	12 Cow(s)	19.81 %	32.09 %	22.86 %	37.04 %
4.0	8 Cow(s)	7 Cow(s)	11 Cow(s)	25.82 %	41.83 %	24.82 %	40.20 %
4.5	5 Cow(s)	5 Cow(s)	8 Cow(s)	25.78 %	41.77 %	26.77 %	43.36 %
5.0	4 Cow(s)	2 Cow(s)	5 Cow(s)	24.03 %	38.93 %	28.72 %	46.53 %
5.5	3 Cow(s)	2 Cow(s)	3 Cow(s)	22.79 %	36.92 %	30.67 %	49.69 %
6.0	2 Cow(s)	1 Cow(s)	2 Cow(s)	22.56 %	36.55 %	32.63 %	52.85 %
6.5	1 Cow(s)	0 Cow(s)	1 Cow(s)	19.86 %	32.18 %	34.58 %	56.02 %
7.0	1 Cow(s)	0 Cow(s)	2 Cow(s)	16.54 %	26.80 %	36.53 %	59.18 %
7.5	0 Cow(s)	0 Cow(s)	1 Cow(s)	16.54 %	26.80 %	38.48 %	62.34 %
8.0	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	40.44 %	65.51 %
8.5	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	42.39 %	68.67 %
9.0	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	44.34 %	71.84 %
9.5	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	46.30 %	75.00 %

4.6. Optimization results

Under default circumstances, the linear programming model determined that the lowest cost was always with some antibiotics but not full BDCT. This can be seen in table 5, where the three herds with different bulk tank SCC are shown. This table is also the answer to the third and final sub question posed in the introduction. It is obvious that multiparous cows have higher cost, this is due to the fact they have a higher incidence rate. Furthermore, it can be seen that the low BTSCC farm have a lower cost in all cases, while the high BTSCC farm always has a higher cost. Also, this is related to the incidence rate. The higher the incidence rate, the more cows get mastitis, more mastitis equals more milk lost, and thus more money lost. Plus, the added cost of having to treat the cows during lactation. This is a trend that is observed throughout all the results.

Table 5. The optimal cost of dry cow treatment according to the linear programming model. The costs are split between primiparous and multiparous, and per bulk tank example herd. Three example herds can be seen, labeled for their BTSCC. Where low is a BTSCC of 111000 and high is a bulk tank of 217000, average sits in between with 155000. The cost herd row shows the cost for a herd with 2440 lactating cows. All costs are in US dollars per year.

	Average herd		*Low BTSCC*		*High BTSCC*	
	Primi-parous	*Multi-parous*	*Primi-parous*	*Multi-parous*	*Primi-parous*	*Multi-parous*
Total cost	10,332	19,396	10,290	18,294	12,822	22,124
Cost per cow	33	56	29	51	36	63
Antibiotic percentage	23%	77%	16%	67%	32%	89%
Cost herd	10,8462		97,188		120,993	

In table 6 the cost for each cow, per example herd, per percentage antibiotic used and split between primiparous and multiparous cows is shown. 100% antibiotic percentage is equal to BDCT, everything below classifies as SDCT because it requires selecting cows and reducing dry cow antibiotics. The cost varied from 78 $ per multiparous cow in a high BTSCC farm to 29 $ per primiparous cow in a low BTSCC farm.

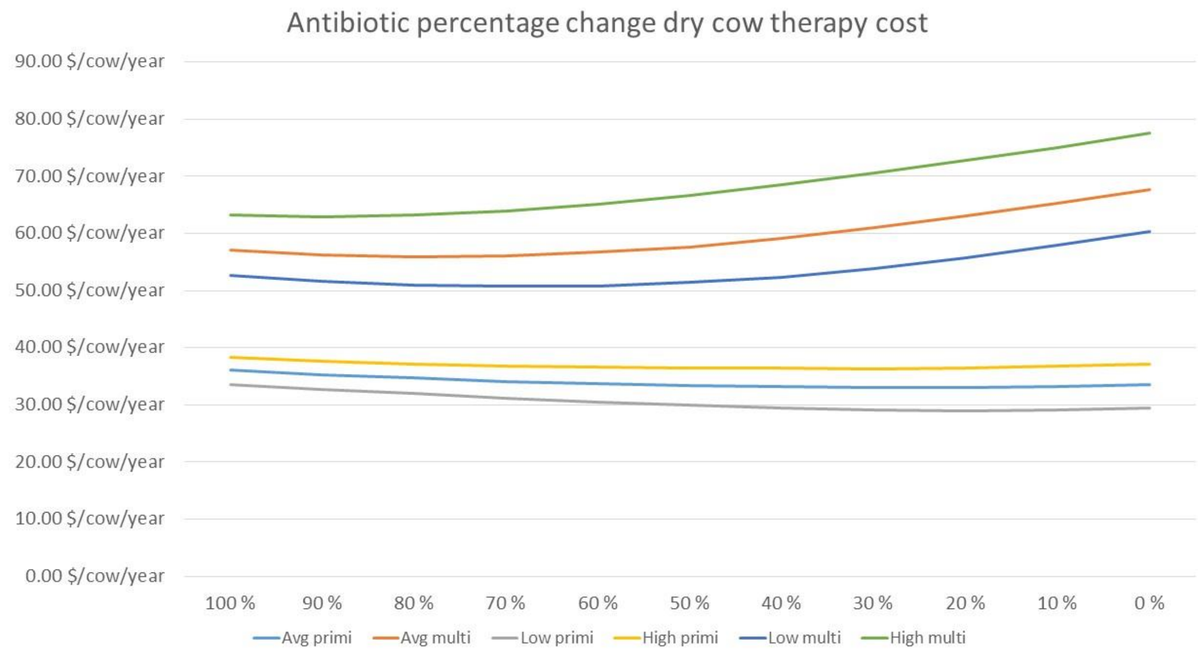
Table 6. Antibiotics percentage restricted per 10% usage. Optimized cost per cow for each type of example herd at different percentages of antibiotics used, split for parity. Three example herds can be seen, labeled for their BTSCC. Where low is a BTSCC of 111000 and high is a bulk tank of

217000, average sits in between with 155000. The total cost rows are in case of a herd with 2440 lactating cows. All costs shown are in US dollars per year.

Anti-biotic %	*Average herd*			*Low BTSCC*			*High BTSCC*		
	Primi-parous	*Multi-parous*	*Total*	*Primi-parous*	*Multi-parous*	*Total*	*Primi-parous*	*Multi-parous*	*Total*
100 %	36	57	113,741	33	53	105,005	38	63	123,781
90 %	35	56	111,752	33	52	102,895	38	63	122,610
80 %	35	56	110,556	32	51	101,150	37	63	122,427
70 %	34	56	110,056	31	51	99,894	37	64	122,915
60 %	34	57	110,239	31	51	99,259	37	65	124,147
50 %	33	58	111,020	30	51	99,296	36	67	125,806
40 %	33	59	112,582	29	52	99,881	36	68	127,893
30 %	33	61	114,643	29	54	101,333	36	71	130,418
20 %	33	63	117,230	29	56	103,371	36	73	133,285
10 %	33	65	120,207	29	58	106,128	37	75	136,396
0 %	34	68	123,623	29	60	109,471	37	78	139,910

The results provided in table 6 are visually summarized in figure The figure provides a faster overview of the change that is happening with each different selected antibiotic percentage allowed during the dry cow treatment. The multiparous curves are slightly basin shaped, with both 100% and 0% antibiotic usage are not the lowest points. The primiparous curves have a downward trend from 100% towards 0% antibiotics, but with a slight upward tail end, so both 100% and 0% antibiotics used are not the lowest cost point.

Figure 7. Cost of dry cow therapy per amount of antibiotics used. The light blue line is the average herd primiparous cow cost per year for dry cow therapy. Orange is the average multiparous cow, grey is low BTSCC herd primiparous cow, yellow is high BTSCC herd primiparous cow, dark blue is low BTSCC herd multiparous and the green line is high BTSCC herd multiparous cow cost per year for dry cow therapy. In the appendix figure A-1 the same graph is provided with symbols at the lowest cost points.



4.7. Sensitivity analysis

The optimal level of antibiotic use was strongly influenced by input costs and the no antibiotics DCT penalty which is the change in infection chance when no antibiotics are used. Milk price is a fluctuating factor every farmer deals with, so this specific factor was altered to represent changes that are likely to occur. The minimum milk price in the sensitivity analysis was 28 cents per kilo milk; if it would go lower the farmer would be making a loss, so this price was used as. For each milk price a new optimal level of antibiotic DCT was found, with different associated costs for mastitis. The sensitivity analysis further supports answering the last question of the introduction: How can the costs be optimized.

Table 7. Milk price sensitivity analysis. Optimized cost per cow for each type of example herd at different percentages of antibiotics used for each different milk price, split for parity. Three example herds can be seen, labeled for their BTSCC. Where low is a BTSCC of 111000 and high is a bulk tank of 217000, average sits in between with 155000. The total cost rows are in case of a herd with 2440 lactating cows. All costs shown are in US dollars per year

Milk price	*Anti-biotic %*	*Average herd*			*Low BTSCC*			*High BTSCC*		
		Primiparous	*Multiparous*	*Total*	*Primiparous*	*Multiparous*	*Total*	*Primiparous*	*Multiparous*	*Total*
0.28 $	Optimal	31	54	103,651	27	49	92,610	34	61	115,973
		0.22%	0.77%		0.15%	0.49%		0.30%	0.89%	
	0 %	32	65	117,327	28	57	103,676	35	74	133,053
	100%	35	55	109,849	32	51	101,431	37	61	119,560
0. 30$	Optimal	31	54	104,456	28	49	93,367	35	61	116,815
		0.23%	0.77%		0.16%	0.67%		0.31%	0.89%	
	0%	32	65	118,377	28	58	104,639	35	75	134,200
	100%	35	56	110,508	33	51	102,016	37	61	120,268
0. 40 $	Optimal	33	56	108,462	29	51	97,188	36	63	120,993
		0.23%	0.77%		0.16%	0.67%		0.32%	0.89%	
	0%	34	68	123,623	29	60	109,471	37	78	139,910
	100%	36	57	113,741	33	53	105,005	38	63	123,781

0. 50 $	Optimal	35	58	112,435	30	52	100,967	38	65	125,135
		0.31 %	0.78 %		0.21 %	0.69 %		0.43 %	0.91 %	
	0%	35	70	128,881	31	63	114,302	39	80	145,607
	100%	37	59	116,986	34	54	107,982	39	65	127,307
0. 60$	Optimal	36	59	116,315	32	54	104,713	39	66	129,113
		0.37 %	0.78 %		0.23 %	0.69 %		0.52 %	0.91 %	
	0%	37	73	134,139	33	65	119,133	41	83	151,317
	100%	38	60	120,219	35	56	110,959	41	67	130,833

The DCT no antibiotics penalty of 62% is purely literature based and thus this was also altered in the sensitivity analysis to reflect different situations. The DCT without administering antibiotics penalty is the amount of increased infection rate after the dry period for cows that do not receive antibiotics at dry off relative to the infection rate of cows that receive antibiotics, like all the cows in a BDCT dairy. The lowest penalty is 0% where the infection rate is not any different from the infection rate of cows that always receive antibiotics at dry off. The highest penalty is 100%, so the infection rate is double the mastitis infection rate for cows that receive antibiotics.

Table 8. DCT no antibiotics infection rate penalty fluctuations for the average herd. Optimized cost per cow at different percentages of antibiotics used for each different penalty, split for parity. The total cost rows are in case of a herd with 2440 lactating cows. All costs shown are in US dollars per year.

No antibiotics DCT infection penalty	*Antibiotic %*	*Average herd*		
		Primiparous	*Multiparous*	*Total*
0 %	Optimal	25	46	86,388
		0%	0%	
	0%	25	46	86,388
	100%	36	57	113,741
25 %	Optimal	28	54	100,284
		0%	37%	
	0%	28	55	101,406
	100%	36	57	113,741
50 %	Optimal	32	56	106,616
		4%	72%	
	0%	32	64	116,412
	100%	36	57	113,741
62 %	Optimal	33	56	108,462
		23%	77%	
	0%	34	68	123,623
	100%	36	57	113,741
75 %	Optimal	34	56	109,934
		44%	81%	
	0%	35	72	131,431
	100%	36	57	113,741
100 %	Optimal	34	56	110,715
		65%	88%	
	0%	39	81	146,461
	100%	36	57	113,741

Finally, the no antibiotics DCT penalty was altered to find the maximum percentage of increased infections for cows dried without antibiotics the optimal amount of antibiotics remained 0%. In other words, this is the DCT without antibiotics penalty at which point the cost for using no antibiotics at all was lower than using antibiotics for all cows, or the break-even point. In the average example herd this point was reached at 38% for primiparous cows and 18% for multiparous cows. For an average herd where cows that receive no antibiotics the increased infection rates, relative to cows that do receive antibiotics at dry off, are lower than 38% and 18% for primiparous and multiparous respectively, it is more cost effective to use no antibiotics at all at the dry period.

5. Discussion

5.1 Current results

Mastitis is a very costly disease, which is known to dairy farmers all over the world, and is shown again in this research (Huijps et al., 2008; Scherpenzeel et al., 2018). Although these are not the total cost of mastitis for a whole farm. This research looks at failure cost in the early days of lactation and only the preventive cost related to the dry period. Failure costs are costs incurred by a case of mastitis such as loss of milk or a veterinary visit. Preventive costs are costs incurred to decrease the incidence of mastitis, such as different bedding, or antibiotics in the dry period (van Soest et al., 2016). The final aim is to reduce both costs, but this study is limited to the time immediately after the dry period. The results show that SDCT is more cost beneficial in this time period, which is also what other studies found (Huijps & Hogeveen, 2007; Scherpenzeel et al., 2016, Scherpenzeel et al., 2018). This is the first study that assesses economics of SDCT in California, so in that aspect it is unique.

The logistic regression to study the ability of SCS before drying off to predict subclinical mastitis infection chance was assessed with a ROC curve (Fan et al., 2006). The AUC is very small, only barely above the 0.5 chance rate. While this means the model is not a very sensitive and specific model, it shows that SCS does help predict the mastitis status after the dry period (Flach, 2016). The small AUC can be attributed to the amount of noise a large dataset with many variables has. Furthermore mastitis is influenced by much more than only SCS before drying off (Bradley, 2002; Steeneveld et al., 2008; van Soest et al., 2019). ROC curves and AUC are often used in machine learning to assess model performance, here it is slightly less important. The predicting power of SCS before the dry period is supported by the P values found in the logistic regression summary. These are statistically significant. So, while the logistic regression model has poor predictive power, it still shows that SCS before drying off has a significant effect on mastitis status after the dry period. Which is why the predicted values were useful as input for a linear regression. This remains a rough approach and could be refined in future work. SCC has been used before to predict clinical mastitis and is seen as one of the major risk factors indicating clinical mastitis (Green et al., 2004; Steeneveld et al., 2008).

The regression analysis for clinical mastitis for multiparous cows shows a downward trend above SCS 4. The SCS categories above 7 were grouped because of low sample sizes in these high categories. While this reduces the amount of categories, many studies do not research SCS as high as 7 (Bradley, 2002; Green et al., 2004; Scherpenzeel et al., 2018), so 7 is not a low category to start grouping. Biologically it is difficult to explain the downward trend, it could be a human factor contributing to cows with high SCS before drying off having less clinical mastitis after the dry period. This also meant a linear function could not be fitted to the relation between probability of clinical mastitis and the SCS before drying off. Therefore, the predicted data points from the logistic regression were directly used. Furthermore, the downward trend means it is not possible to give one specific SCS to start drying off with antibiotics, so antibiotic percentages are given as results. This is complicated further by the fact primiparous and multiparous have different optimal points. So, there is no logical SCS cut off value but a percentage of antibiotics that should be used.

Cost of mastitis was based on multiple inputs, which can be seen in table 2. These costs were based on expert knowledge of dairies in California. The sensitivity analysis shows that cost greatly influences the total mastitis cost per dry cow treatment. If milk or feed price changes, the cost of antibiotics and the optimal SCS to select cows for antibiotics, will change too. The antibiotic cost will change because if less dry cow antibiotics are used, more lactational antibiotics are necessary to treat the increased amount of mastitis in the herd in the next lactation. (Scherpenzeel et al., 2018). The total change including both lactational and dry treatment antibiotics will still mean fewer antibiotics (Vanhoudt et al., 2018). The sensitivity analysis could be expanded to account for these changes, but it would remain theoretical. Also, it is assumed that the farms using BDCT also use an internal teat sealant, which is a major cost. When a dairy does not use this, it will most likely change the cost, and thus the output. If a farmer doing SDCT chooses not to use teat sealants, this also would be a major cost reduction, but it comes with a large increase to infection rate after the dry period, which is also a reason the no antibiotics DCT penalty was analyzed as this was based on infection rates without teat sealants (Rabiee & Lean, 2013). It is a limitation in this study, the data is of only a specific point in time for mostly average herds.

The example herds constructed after Californian dairies are based on dairy herd improvement data. Dairies that join the program could be paying more attention to animal welfare and dairy management. Thus, giving a skewed representation of the total state. Furthermore, the core herds that are used to calculate the CM, work closely with UC Davis. The sample size is not as large as the dairy herd improvement data, and the farms are actively managing their cows. These farms could have distinct data relative to other farms, due to their close contact with UC Davis. Besides that, each farmer is different (van Soest et al., 2019). They use different systems, facilities, labor force, machines, feed and have different mindsets. So, the data used are averages, but each dairy is unique. This means there is an opportunity for a tool.

This argument could also be made for mastitis, each case of mastitis and each cow involved is unique. These are organisms, and not machines. Different pathogens could elongate or shorten a mastitis case. Production loss is different per cow, per pathogen and per case. Milk yield patterns can change depending on the pathogen, but also during a mastitis case (Gröhn et al., 2004). In this study differences between pathogens and milk yield loss patterns were not considered, as this would add a layer of complexity that could not be modeled at this time.

A major discussion point is the no antibiotics DCT penalty, this is purely based on literature and can fluctuate a lot between dairies. The sensitivity analysis and the break-even analysis were done to show farmers what their infection rates should be for an effective SDCT program. Also, it alleviated the literature-based aspect of the penalty. The sensitivity analysis could be broadened to include different brands of antibiotics which each have different costs, changes in feed, veterinary and culling cost and farm specific inputs such as stalls and parlor practices.

The turnover inputs and other cost inputs were based on expert knowledge. These could be different per region and change over time. These changes were not tested with a sensitivity analysis, but they could influence the optimal cost.

Finally, one could argue that the costs are not complete. The cost of illness when antibiotic resistance would occur are not calculated for BDCT. The BDCT contributes to antibiotic resistance, something which already causes deaths and prolonged illness (CDC, 2019).If it develops further the economic costs can reach billions yearly and are in some ways incalculable, because the health care system is not set to tackle this issue (Hofer, 2019; Smith & Coast, 2013). Which is also one of the reasons this cost could not be included. Furthermore, it is unknown how much BDCT contributes to the whole problem. To calculate this, and the cost of antibiotic resistance is outside the scope of this study. It would be interesting to see what the final total would become if the cost of combatting antibiotic resistance is also considered.

5.2 Future perspective

Eventually a tool can be developed which farmers can use with their own specific data to calculate cost and make an effective and cost efficient SDCT plan. This tool should be user friendly and not take too much time and need for inputs, while giving an accurate estimation of cost difference for a specific farm between a BDCT and a SDCT dry plan while reducing net amount of antibiotics. Net antibiotics decrease is where the total amount of antibiotics decreases, both dry antibiotics and lactational antibiotics. This tool could include dairy specific data, mastitis pathogen data and the ability to input a farmer's own no antibiotics DCT penalty. An optimal balance point with accurate cost per specific farm would be the outcome. A tailor-made result can ensure dairymen take the most advantage possible.

These results show that it is time to take steps towards a SDCT state in California. Especially for farms with a low BTSCC SDCT is economically beneficial, these farms should be the first to make steps towards implementing a SDCT plan. In the future policy makers could decide to make SDCT mandatory, such as in the Netherlands (Scherpenzeel et al., 2016). Economically this should not be a problem for any farmer. Perhaps they can provide the proposed tool and other guidance to make an optimized plan per farm. California could set an example for the rest of the United States, making the whole dairy sector in the US more antibiotic friendly. This could inspire other sectors to become more prudent with their antibiotic uses too, making a significant impact on antibiotic resistance development all together.

6. Conclusion

SDCT costs less in all cases than BDCT in California. The main question at what point is SDCT economically equal or more beneficial than BDCT in large dairy herds in California can thus be answered. It is more beneficial economically in all cases in California. Some important differences between each situation were observed, namely: primiparous and multiparous, the three example herds and the relative increased no antibiotics infection rate in the form of a penalty.

The difference in infection chance between primiparous and multiparous cows meant that usually less antibiotics could be used for, whilst keeping the cost low, primiparous cows than multiparous. The three different farms also behaved like expected, where the high BTSCC farm had the highest cost, however it was still more cost effective to select cows during the drying plan than using BDCT. Impressively the primiparous cows receiving no antibiotics need to have 39% more infections in the new lactation than cows receiving antibiotics at dry off before the use of any percentage of antibiotics at dry off becomes more beneficial economically. For multiparous this is slightly lower, with 19%.

These results show that SDCT is cost effective in California. Antibiotics can be reduced while profits can increase. So, farmers can contribute to the fight against antibiotic resistance and for consumer safety, while reaping benefits for their cattle and wallets.

7. Acknowledgements

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Thank you to all the dairies who participated, and a special thanks to the Van Beek Brothers' dairy and the family Van Beek for giving me the warmest welcome and arranging my debut to Californian dairy management.

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8. References

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9. Appendix

Table A-1. Primiparous distribution and corresponding clinical and subclinical incidence rate in dairy herds of 1000 dairy cattle. Three example herds can be seen, labeled for their BTSCC. Where low is a BTSCC of 111000 and high is a bulk tank of 217000, average sits in between with 155000. The incidence rates were determined with the above described regression methods. The infection rate of cows that received at antibiotics at drying off are in the column "Antibiotics" (1). Here the DCT with no antibiotics base penalty of 62% is used to fill the columns "No antibiotics" (2). This is the full table were table 3 is extracted from.

SCS	*Average Primi-parous*	*Low Primi-parous*	*High Primi-parous*	*Clinical Mastitis*		*Subclinical mastitis*	
				Antibiotics (1)	*No antibiotics (2)*	*Antibiotics (1)*	*No antibiotics (2)*
0.1	4 Cow(s)	72 Cow(s)	2 Cow(s)	2.89 %	4.68 %	10.19 %	16.51 %
0.2	5 Cow(s)	9 Cow(s)	0 Cow(s)	3.44 %	5.58 %	10.38 %	16.82 %
0.3	6 Cow(s)	13 Cow(s)	1 Cow(s)	3.83 %	6.20 %	10.57 %	17.13 %
0.4	11 Cow(s)	20 Cow(s)	3 Cow(s)	2.88 %	4.66 %	10.76 %	17.44 %
0.5	6 Cow(s)	6 Cow(s)	0 Cow(s)	3.19 %	5.17 %	10.95 %	17.74 %
0.6	6 Cow(s)	4 Cow(s)	2 Cow(s)	3.95 %	6.40 %	11.14 %	18.05 %
0.7	11 Cow(s)	15 Cow(s)	5 Cow(s)	4.35 %	7.05 %	11.33 %	18.36 %
0.8	5 Cow(s)	6 Cow(s)	3 Cow(s)	3.91 %	6.34 %	11.52 %	18.67 %

0.9	10 Cow(s)	11 Cow(s)	3 Cow(s)	4.48 %	7.26 %	11.71 %	18.98 %
1	5 Cow(s)	7 Cow(s)	5 Cow(s)	4.47 %	7.24 %	11.91 %	19.29 %
1.1	9 Cow(s)	9 Cow(s)	2 Cow(s)	3.31 %	5.36 %	12.10 %	19.59 %
1.2	8 Cow(s)	7 Cow(s)	4 Cow(s)	4.64 %	7.52 %	12.29 %	19.90 %
1.3	7 Cow(s)	7 Cow(s)	5 Cow(s)	4.18 %	6.77 %	12.48 %	20.21 %
1.4	9 Cow(s)	7 Cow(s)	10 Cow(s)	4.34 %	7.04 %	12.67 %	20.52 %
1.5	5 Cow(s)	4 Cow(s)	9 Cow(s)	4.98 %	8.07 %	12.86 %	20.83 %
1.6	7 Cow(s)	6 Cow(s)	9 Cow(s)	5.41 %	8.76 %	13.05 %	21.14 %
1.7	7 Cow(s)	8 Cow(s)	7 Cow(s)	6.93 %	11.22 %	13.24 %	21.45 %
1.8	8 Cow(s)	6 Cow(s)	9 Cow(s)	7.59 %	12.30 %	13.43 %	21.75 %
1.9	7 Cow(s)	5 Cow(s)	6 Cow(s)	6.15 %	9.97 %	13.62 %	22.06 %
2	8 Cow(s)	9 Cow(s)	10 Cow(s)	5.72 %	9.26 %	13.81 %	22.37 %
2.1	9 Cow(s)	7 Cow(s)	9 Cow(s)	6.55 %	10.61 %	14.00 %	22.68 %
2.2	9 Cow(s)	6 Cow(s)	13 Cow(s)	5.75 %	9.31 %	14.19 %	22.99 %
2.3	8 Cow(s)	10 Cow(s)	9 Cow(s)	6.52 %	10.56 %	14.38 %	23.30 %

2.4	9 Cow(s)	5 Cow(s)	11 Cow(s)	7.06 %	11.44 %	14.57 %	23.61 %
2.5	9 Cow(s)	9 Cow(s)	9 Cow(s)	5.83 %	9.45 %	14.76 %	23.91 %
2.6	8 Cow(s)	8 Cow(s)	9 Cow(s)	9.31 %	15.08 %	14.95 %	24.22 %
2.7	8 Cow(s)	8 Cow(s)	13 Cow(s)	8.26 %	13.39 %	15.14 %	24.53 %
2.8	8 Cow(s)	5 Cow(s)	15 Cow(s)	7.96 %	12.89 %	15.33 %	24.84 %
2.9	7 Cow(s)	3 Cow(s)	13 Cow(s)	7.11 %	11.53 %	15.52 %	25.15 %
3	7 Cow(s)	3 Cow(s)	14 Cow(s)	7.80 %	12.64 %	15.71 %	25.46 %
3.1	6 Cow(s)	8 Cow(s)	10 Cow(s)	10.33 %	16.73 %	15.90 %	25.77 %
3.2	6 Cow(s)	7 Cow(s)	8 Cow(s)	9.85 %	15.96 %	16.10 %	26.07 %
3.3	6 Cow(s)	1 Cow(s)	9 Cow(s)	7.81 %	12.66 %	16.29 %	26.38 %
3.4	6 Cow(s)	3 Cow(s)	8 Cow(s)	9.35 %	15.15 %	16.48 %	26.69 %
3.5	5 Cow(s)	4 Cow(s)	9 Cow(s)	11.62 %	18.83 %	16.67 %	27.00 %
3.6	5 Cow(s)	4 Cow(s)	9 Cow(s)	10.25 %	16.60 %	16.86 %	27.31 %
3.7	5 Cow(s)	1 Cow(s)	7 Cow(s)	9.65 %	15.63 %	17.05 %	27.62 %
3.8	4 Cow(s)	4 Cow(s)	5 Cow(s)	9.87 %	15.98 %	17.24 %	27.93 %

3.9	4 Cow(s)	4 Cow(s)	8 Cow(s)	10.33 %	16.74 %	17.43 %	28.23 %
4	4 Cow(s)	1 Cow(s)	4 Cow(s)	10.04 %	16.27 %	17.62 %	28.54 %
4.1	3 Cow(s)	1 Cow(s)	6 Cow(s)	10.03 %	16.24 %	17.81 %	28.85 %
4.2	3 Cow(s)	1 Cow(s)	5 Cow(s)	7.69 %	12.46 %	18.00 %	29.16 %
4.3	3 Cow(s)	1 Cow(s)	4 Cow(s)	8.16 %	13.22 %	18.19 %	29.47 %
4.4	3 Cow(s)	1 Cow(s)	6 Cow(s)	10.22 %	16.56 %	18.38 %	29.78 %
4.5	2 Cow(s)	1 Cow(s)	4 Cow(s)	10.19 %	16.50 %	18.57 %	30.09 %
4.6	2 Cow(s)	1 Cow(s)	2 Cow(s)	7.73 %	12.53 %	18.76 %	30.39 %
4.7	2 Cow(s)	1 Cow(s)	2 Cow(s)	11.61 %	18.81 %	18.95 %	30.70 %
4.8	2 Cow(s)	1 Cow(s)	4 Cow(s)	7.19 %	11.65 %	19.14 %	31.01 %
4.9	2 Cow(s)	1 Cow(s)	3 Cow(s)	7.64 %	12.38 %	19.33 %	31.32 %
5	2 Cow(s)	1 Cow(s)	3 Cow(s)	9.02 %	14.61 %	19.52 %	31.63 %
5.1	1 Cow(s)	0 Cow(s)	2 Cow(s)	7.60 %	12.32 %	19.71 %	31.94 %
5.2	1 Cow(s)	1 Cow(s)	2 Cow(s)	12.29 %	19.91 %	19.90 %	32.25 %
5.3	1 Cow(s)	1 Cow(s)	3 Cow(s)	14.38 %	23.30 %	20.09 %	32.55 %

5.4	1 Cow(s)	1 Cow(s)	1 Cow(s)	10.50 %	17.02 %	20.29 %	32.86 %
5.5	1 Cow(s)	0 Cow(s)	1 Cow(s)	12.09 %	19.58 %	20.48 %	33.17 %
5.6	1 Cow(s)	1 Cow(s)	1 Cow(s)	8.65 %	14.02 %	20.67 %	33.48 %
5.7	1 Cow(s)	0 Cow(s)	3 Cow(s)	6.74 %	10.92 %	20.86 %	33.79 %
5.8	1 Cow(s)	0 Cow(s)	1 Cow(s)	6.13 %	9.94 %	21.05 %	34.10 %
5.9	1 Cow(s)	0 Cow(s)	2 Cow(s)	12.07 %	19.55 %	21.24 %	34.41 %
6	1 Cow(s)	1 Cow(s)	0 Cow(s)	13.14 %	21.28 %	21.43 %	34.71 %
6.1	1 Cow(s)	1 Cow(s)	2 Cow(s)	7.63 %	12.36 %	21.62 %	35.02 %
6.2	1 Cow(s)	1 Cow(s)	2 Cow(s)	2.73 %	4.42 %	21.81 %	35.33 %
6.3	0 Cow(s)	1 Cow(s)	0 Cow(s)	11.61 %	18.80 %	22.00 %	35.64 %
6.4	0 Cow(s)	1 Cow(s)	2 Cow(s)	9.20 %	14.90 %	22.19 %	35.95 %
6.5	0 Cow(s)	1 Cow(s)	0 Cow(s)	5.08 %	8.24 %	22.38 %	36.26 %
6.6	0 Cow(s)	0 Cow(s)	1 Cow(s)	8.93 %	14.46 %	22.57 %	36.56 %
6.7	0 Cow(s)	0 Cow(s)	0 Cow(s)	2.27 %	3.68 %	22.76 %	36.87 %
6.8	0 Cow(s)	0 Cow(s)	1 Cow(s)	12.50 %	20.25 %	22.95 %	37.18 %

6.9	0 Cow(s)	1 Cow(s)	0 Cow(s)	11.11 %	18.00 %	23.14 %	37.49 %
7	0 Cow(s)	0 Cow(s)	2 Cow(s)	6.06 %	9.81 %	23.33 %	37.80 %
7.1	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	23.52 %	38.11 %
7.2	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	23.71 %	38.42 %
7.3	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	23.90 %	38.72 %
7.4	0 Cow(s)	1 Cow(s)	0 Cow(s)	6.06 %	9.81 %	24.09 %	39.03 %
7.5	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	24.29 %	39.34 %
7.6	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	24.48 %	39.65 %
7.7	0 Cow(s)	0 Cow(s)	1 Cow(s)	6.06 %	9.81 %	24.67 %	39.96 %
7.8	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	24.86 %	40.27 %
7.9	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	25.05 %	40.58 %
8	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	25.24 %	40.88 %
8.1	0 Cow(s)	1 Cow(s)	0 Cow(s)	6.06 %	9.81 %	25.43 %	41.19 %
8.2	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	25.62 %	41.50 %
8.3	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	25.81 %	41.81 %

8.4	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	26.00 %	42.12 %
8.5	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	26.19 %	42.43 %
8.6	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	26.38 %	42.74 %
8.7	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	26.57 %	43.04 %
8.8	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	26.76 %	43.35 %
8.9	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	26.95 %	43.66 %
9	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	27.14 %	43.97 %
9.1	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	27.33 %	44.28 %
9.2	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	27.52 %	44.59 %
9.3	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	27.71 %	44.90 %
9.4	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	27.90 %	45.20 %
9.5	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	28.09 %	45.51 %
9.6	0 Cow(s)	0 Cow(s)	0 Cow(s)	6.06 %	9.81 %	28.28 %	45.82 %

Table A-2. Multiparous distribution and corresponding clinical and subclinical incidence rate in dairy herds of 1000 dairy cattle. Three example herds can be seen, labeled for their BTSCC. Where low is a BTSCC of 111000 and high is a bulk tank of 217000, average sits in between with 155000. The incidence rates were determined with the above described regression methods. The infection rate of cows that received at antibiotics at drying off are in the column "Antibiotics" (1). Here the DCT with no antibiotics base penalty of 62% is used to fill the columns "No antibiotics" (2). This is the full table were table 4 is extracted from.

SCS	*Average Multi-parous*	*Low Multi-parous*	*High Multi-parous*	*Clinical Mastitis Antibiotics (1)*	*Clinical Mastitis No antibiotics (2)*	*Subclinical mastitis Antibiotics (1)*	*Subclinical mastitis No antibiotics (2)*
0.1	8 Cow(s)	10 Cow(s)	0 Cow(s)	0.52 %	0.84 %	9.58 %	15.53 %
0.2	1 Cow(s)	4 Cow(s)	0 Cow(s)	1.37 %	2.23 %	9.98 %	16.16 %
0.3	1 Cow(s)	4 Cow(s)	0 Cow(s)	1.32 %	2.13 %	10.37 %	16.79 %
0.4	3 Cow(s)	5 Cow(s)	0 Cow(s)	2.30 %	3.72 %	10.76 %	17.42 %
0.5	2 Cow(s)	4 Cow(s)	0 Cow(s)	1.74 %	2.82 %	11.15 %	18.06 %
0.6	2 Cow(s)	2 Cow(s)	0 Cow(s)	2.80 %	4.53 %	11.54 %	18.69 %
0.7	4 Cow(s)	8 Cow(s)	0 Cow(s)	2.27 %	3.68 %	11.93 %	19.32 %
0.8	2 Cow(s)	2 Cow(s)	0 Cow(s)	2.29 %	3.70 %	12.32 %	19.96 %
0.9	4 Cow(s)	5 Cow(s)	1 Cow(s)	2.33 %	3.78 %	12.71 %	20.59 %
1	2 Cow(s)	1 Cow(s)	0 Cow(s)	2.66 %	4.31 %	13.10 %	21.22 %
1.1	4 Cow(s)	7 Cow(s)	1 Cow(s)	3.57 %	5.79 %	13.49 %	21.85 %
1.2	4 Cow(s)	7 Cow(s)	2 Cow(s)	3.36 %	5.44 %	13.88 %	22.49 %
1.3	3 Cow(s)	5 Cow(s)	2 Cow(s)	6.01 %	9.73 %	14.27 %	23.12 %
1.4	4 Cow(s)	11 Cow(s)	4 Cow(s)	4.56 %	7.39 %	14.66 %	23.75 %
1.5	3 Cow(s)	4 Cow(s)	3 Cow(s)	5.46 %	8.85 %	15.05 %	24.38 %
1.6	4 Cow(s)	5 Cow(s)	3 Cow(s)	6.81 %	11.04 %	15.44 %	25.02 %
1.7	5 Cow(s)	6 Cow(s)	4 Cow(s)	6.32 %	10.25 %	15.83 %	25.65 %
1.8	5 Cow(s)	6 Cow(s)	3 Cow(s)	6.16 %	9.98 %	16.22 %	26.28 %
1.9	6 Cow(s)	8 Cow(s)	6 Cow(s)	8.17 %	13.24 %	16.61 %	26.92 %
2	6 Cow(s)	6 Cow(s)	4 Cow(s)	5.59 %	9.05 %	17.00 %	27.55 %

2.1	8 Cow(s)	9 Cow(s)	5 Cow(s)	7.17 %	11.62 %	17.40 %	28.18 %
2.2	8 Cow(s)	12 Cow(s)	6 Cow(s)	9.61 %	15.56 %	17.79 %	28.81 %
2.3	8 Cow(s)	10 Cow(s)	5 Cow(s)	10.30 %	16.68 %	18.18 %	29.45 %
2.4	10 Cow(s)	10 Cow(s)	10 Cow(s)	11.21 %	18.16 %	18.57 %	30.08 %
2.5	9 Cow(s)	8 Cow(s)	9 Cow(s)	11.53 %	18.68 %	18.96 %	30.71 %
2.6	9 Cow(s)	8 Cow(s)	7 Cow(s)	12.46 %	20.19 %	19.35 %	31.34 %
2.7	10 Cow(s)	16 Cow(s)	11 Cow(s)	14.05 %	22.76 %	19.74 %	31.98 %
2.8	10 Cow(s)	6 Cow(s)	9 Cow(s)	14.15 %	22.92 %	20.13 %	32.61 %
2.9	9 Cow(s)	10 Cow(s)	8 Cow(s)	14.26 %	23.10 %	20.52 %	33.24 %
3	10 Cow(s)	11 Cow(s)	12 Cow(s)	15.48 %	25.08 %	20.91 %	33.87 %
3.1	10 Cow(s)	10 Cow(s)	12 Cow(s)	19.22 %	31.14 %	21.30 %	34.51 %
3.2	10 Cow(s)	11 Cow(s)	10 Cow(s)	19.05 %	30.86 %	21.69 %	35.14 %
3.3	10 Cow(s)	13 Cow(s)	12 Cow(s)	19.75 %	32.00 %	22.08 %	35.77 %
3.4	10 Cow(s)	8 Cow(s)	13 Cow(s)	19.07 %	30.89 %	22.47 %	36.41 %
3.5	9 Cow(s)	10 Cow(s)	12 Cow(s)	19.81 %	32.09 %	22.86 %	37.04 %
3.6	9 Cow(s)	8 Cow(s)	14 Cow(s)	23.30 %	37.74 %	23.25 %	37.67 %
3.7	9 Cow(s)	6 Cow(s)	10 Cow(s)	25.00 %	40.50 %	23.64 %	38.30 %

3.8	9 Cow(s)	10 Cow(s)	12 Cow(s)	24.75 %	40.10 %	24.03 %	38.94 %
3.9	8 Cow(s)	9 Cow(s)	12 Cow(s)	24.10 %	39.04 %	24.43 %	39.57 %
4	8 Cow(s)	7 Cow(s)	11 Cow(s)	25.82 %	41.83 %	24.82 %	40.20 %
4.1	7 Cow(s)	5 Cow(s)	11 Cow(s)	22.17 %	35.92 %	25.21 %	40.83 %
4.2	7 Cow(s)	5 Cow(s)	12 Cow(s)	25.21 %	40.84 %	25.60 %	41.47 %
4.3	7 Cow(s)	5 Cow(s)	9 Cow(s)	23.93 %	38.77 %	25.99 %	42.10 %
4.4	6 Cow(s)	2 Cow(s)	7 Cow(s)	27.09 %	43.88 %	26.38 %	42.73 %
4.5	5 Cow(s)	5 Cow(s)	8 Cow(s)	25.78 %	41.77 %	26.77 %	43.36 %
4.6	5 Cow(s)	3 Cow(s)	5 Cow(s)	23.96 %	38.82 %	27.16 %	44.00 %
4.7	5 Cow(s)	5 Cow(s)	4 Cow(s)	26.69 %	43.23 %	27.55 %	44.63 %
4.8	5 Cow(s)	1 Cow(s)	7 Cow(s)	24.24 %	39.27 %	27.94 %	45.26 %
4.9	4 Cow(s)	4 Cow(s)	5 Cow(s)	24.47 %	39.64 %	28.33 %	45.90 %
5	4 Cow(s)	2 Cow(s)	5 Cow(s)	24.03 %	38.93 %	28.72 %	46.53 %
5.1	3 Cow(s)	4 Cow(s)	5 Cow(s)	26.09 %	42.26 %	29.11 %	47.16 %
5.2	3 Cow(s)	1 Cow(s)	5 Cow(s)	25.84 %	41.86 %	29.50 %	47.79 %
5.3	3 Cow(s)	2 Cow(s)	4 Cow(s)	22.87 %	37.06 %	29.89 %	48.43 %
5.4	3 Cow(s)	1 Cow(s)	1 Cow(s)	23.15 %	37.50 %	30.28 %	49.06 %
5.5	3 Cow(s)	2 Cow(s)	3 Cow(s)	22.79 %	36.92 %	30.67 %	49.69 %
5.6	2 Cow(s)	1 Cow(s)	2 Cow(s)	26.07 %	42.23 %	31.06 %	50.32 %
5.7	2 Cow(s)	1 Cow(s)	3 Cow(s)	23.38 %	37.88 %	31.45 %	50.96 %
5.8	2 Cow(s)	1 Cow(s)	1 Cow(s)	21.07 %	34.13 %	31.85 %	51.59 %
5.9	2 Cow(s)	0 Cow(s)	2 Cow(s)	20.10 %	32.57 %	32.24 %	52.22 %
6	2 Cow(s)	1 Cow(s)	2 Cow(s)	22.56 %	36.55 %	32.63 %	52.85 %
6.1	1 Cow(s)	1 Cow(s)	2 Cow(s)	17.11 %	27.72 %	33.02 %	53.49 %
6.2	1 Cow(s)	1 Cow(s)	2 Cow(s)	21.03 %	34.07 %	33.41 %	54.12 %
6.3	1 Cow(s)	2 Cow(s)	1 Cow(s)	27.04 %	43.80 %	33.80 %	54.75 %

6.4	1 Cow(s)	1 Cow(s)	1 Cow(s)	20.22 %	32.76 %	34.19 %	55.39 %
6.5	1 Cow(s)	0 Cow(s)	1 Cow(s)	19.86 %	32.18 %	34.58 %	56.02 %
6.6	1 Cow(s)	1 Cow(s)	1 Cow(s)	23.53 %	38.12 %	34.97 %	56.65 %
6.7	1 Cow(s)	0 Cow(s)	2 Cow(s)	12.04 %	19.50 %	35.36 %	57.28 %
6.8	1 Cow(s)	1 Cow(s)	1 Cow(s)	18.80 %	30.46 %	35.75 %	57.92 %
6.9	1 Cow(s)	0 Cow(s)	1 Cow(s)	12.37 %	20.04 %	36.14 %	58.55 %
7	1 Cow(s)	0 Cow(s)	2 Cow(s)	16.54 %	26.80 %	36.53 %	59.18 %
7.1	1 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	36.92 %	59.81 %
7.2	0 Cow(s)	0 Cow(s)	1 Cow(s)	16.54 %	26.80 %	37.31 %	60.45 %
7.3	0 Cow(s)	0 Cow(s)	1 Cow(s)	16.54 %	26.80 %	37.70 %	61.08 %
7.4	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	38.09 %	61.71 %
7.5	0 Cow(s)	0 Cow(s)	1 Cow(s)	16.54 %	26.80 %	38.48 %	62.34 %
7.6	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	38.88 %	62.98 %
7.7	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	39.27 %	63.61 %
7.8	0 Cow(s)	1 Cow(s)	0 Cow(s)	16.54 %	26.80 %	39.66 %	64.24 %
7.9	0 Cow(s)	0 Cow(s)	1 Cow(s)	16.54 %	26.80 %	40.05 %	64.88 %
8	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	40.44 %	65.51 %
8.1	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	40.83 %	66.14 %
8.2	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	41.22 %	66.77 %
8.3	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	41.61 %	67.41 %
8.4	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	42.00 %	68.04 %
8.5	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	42.39 %	68.67 %
8.6	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	42.78 %	69.30 %
8.7	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	43.17 %	69.94 %
8.8	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	43.56 %	70.57 %
8.9	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	43.95 %	71.20 %
9	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	44.34 %	71.84 %
9.1	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	44.73 %	72.47 %
9.2	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	45.12 %	73.10 %
9.3	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	45.51 %	73.73 %
9.4	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	45.90 %	74.37 %

9.5	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	46.30 %	75.00 %
9.6	0 Cow(s)	0 Cow(s)	0 Cow(s)	16.54 %	26.80 %	46.69 %	75.63 %

Figure A-1. Cost of dry cow therapy per amount of antibiotics used. The light blue line is the average herd primiparous cow cost per year for dry cow therapy. Orange is the average multiparous cow, grey is low BTSCC herd primiparous cow, yellow is high BTSCC herd primiparous cow, dark blue is low BTSCC herd multiparous and the green line is high BTSCC herd multiparous cow cost per year for dry cow therapy. In the text figure 7 the same graph is provided without symbols at the lowest cost points. The diamond is for high BTSCC herd, the oval for average BTSCC herd and the rectangle for low BTSCC herd.