(e.g., Bar et al., 2008; Bennett et al., 1999; Hagnestam-Nielsen and Østergaard, 2009; Nielsen, 2009). Only a few studies have calculated all costs categories including; costs of production loss, drugs, labor, culling, veterinary, discarded milk, and milk quality (SCC), which are needed for correct and adequate economic calculations (Gill et al., 1990; Halasa et al., 2007; Huijips et al., 2008; Rollin et al., 2015; Schepers & Dijkhuizen, 1991). The most common method used to estimate costs of mastitis is dynamic stochastic simulation model, and most of the researchers are from the field of veterinary science, biology, epidemiology, genetics, and a few within the agricultural economics. Estimates from simulations were higher than estimates calculated from other methods (e.g., Bar et al., 2008; Hagnestam-Nielsen & Østergaard, 2009).

3.2 Theoretical framework

The theoretical framework of this study originates from traditional microeconomic theories and managerial economics. Managerial economics deals with the application of economic theories, concepts, tools, and methodologies in order to solve practical problems in business (Allen et al., 2013). The overall purpose of managerial economics is to help the manager in decision making and it acts as a link between practice and theory. Thereby, managerial economics assist the companies in the work of achieving their strategic objectives (Pindyck & Rubinfeld, 2009). Lastly, the study is also based on theories regarding animal health economics.

3.2.1 Production economics

The underlying assumption for any business is to maximize the utility by profit maximization, and the major challenge is for any firm manager to allocate its resources in order to generate a profit (Allen et al., 2013). Profit is the surplus remaining when a firm's total costs are subtracted from its total revenue, and maximum profit has two different dimensions; revenue maximization or cost minimization. Profit maximization occurs when a firm find the level of output (production level) where the slope of the profit function is zero, i.e., where the difference (gap) between total revenue (TR) and total cost (TC) is as big as possible (Allen et al., 2013). Profit maximization also occurs at the point when marginal cost (MC) is equal to marginal revenue (MR), and the point is located somewhere below the maximum output. Hence, producing interminably is not necessarily the most profitable solution (Pindyck & Rubinfeld, 2009).

Understanding the production process, and knowing how to control firm costs, are two key issues in the direction for a firm to become profitable. At the most fundamental level, firms must be as efficient as possible when transforming their scarce resources (inputs) into outputs, but efficiency requires knowledge of the production process (Allen et al., 2013). Firm inputs are known as production factors and include anything that the firm needs for its production process (Pindyck & Rubinfeld, 2009). Usually, the inputs are categorized into three groups: labor, material, and capital. Labor inputs include workers (both skilled, unskilled and firm managers), materials include goods and raw material, bought and transformed into final products, and capital include land, machinery, equipment, buildings, and inventories. There is a variety of ways for firms to turn their inputs into outputs, which can be expressed by a production function. The production function describes the technical relationships transforming inputs into output (Allen et al., 2013). Each firm has a unique production function, and it applies to certain available technology (Pindyck & Rubinfeld, 2009). The general expression for the production function is (1):

$$Q= f(X_1, X_2, \ldots X_n) \quad (1)$$

Where Q is the level of output produced and $X_1, X_2, \ldots X_n$ are the inputs needed. Inputs can be fixed or variable, though, in the long run, all inputs are said to be variable (Pindyck & Rubinfeld, 2009). Fixed inputs are usually buildings, land, machinery, while variable inputs are altering in volume when facing a shift in market conditions (Allen et al., 2013). If there is a disturbance in the production process, it may lower the amount of output, by increasing the inputs needed or reducing the efficiency of the inputs. This will cause a downward shift in the production function due to a reduction in output for a given input level associated with the disturbance (Allen et al., 2013). Managers study the production function in order to gain insight into the firm's cost structure.

If total output remains fixed due to capacity constraints (in the short run) and the revenue streams remain fixed (e.g., prices cannot be changed on its own, due to a competitive market), the only way to maximize profit is for the firm to minimize its costs (Pindyck & Rubinfeld, 2009). A firm's costs include several items distinguished between controllable and those who cannot be controlled (Allen et al., 2013). Together with the firm's production costs, they determine the economic cost of production.

Many times, extensive investments are required for the company to manage different changes. Investments are also made to improve the company's chances for survival (Allen et al., 2013). Strategic investments are a sacrifice of immediate consumption with the aim of strengthening the company by increasing future revenues as a result of the investment. There is not unusual that companies make investments to try to reduce their costs in the long term and thus increase the company's profitability (Pindyck & Rubinfeld, 2009). By replacing existing resources with new ones, or expanding the company's capacity and becoming more efficient, the company can achieve higher profitability.

3.2.2 Animal health economics

Animal health economics is defined by Dijkhuzien (1992) as the discipline that aims to provide a framework of concepts, procedures, and data to support the decision-making process in optimizing animal health management. The research field primarily deals with quantifying economic effects of animal diseases, develop methods for optimizing decisions, and determining the profitability of disease control/health management programs (Dijkhuzien, 1992). Prevention of production animal diseases has become a key element in the development of competitive livestock production systems (Bennett, 2003; Schwabenbauer, 2012). The same applies to control the costs of farm livestock production and to improve animal health and fertility, which also may be crucial to becoming profitable in modern farming (Bennett, 2003; McInerney, 1996).

Diseases in livestock affect the production in different ways, but the common denominator is that diseases reduces the efficiency and decrease the productivity (McInerney, Howe & Schepers, 1992). On the input level, diseases destroy the necessary resources of the production, e.g., mortality of livestock and lowering the efficiency of the production process by reduced feed conversation. Diseases may alter feed intake, which will most likely be reduced which harms the animal and the production (Bennett, 2003). It may affect the nutrient metabolism, respiration or excretion, which all can be costly for the producer and deadly for the animal. At output level, diseases may reduce the amount of output, e.g., lower milk yield, fewer eggs produced, fewer piglets and others. Diseases can also harm the quality of the product, e.g., lower fat content in milk, poor hides because of parasites, and so on (Bennett, 2003). Furthermore, diseases can change the value of animals and products from slaughtered animals, reduce weight gain, fertility, capacity for work and so on. Lastly, some diseases may harm human well-being through zoonoses (McInerney, 1996).

As a result of diseases, losses arise for the producers. Calculating financial losses due to diseases help to analyze the situation, limit the loss as much as possible and estimate the extent of the loss to be avoided (Dijkhuzien & Morris, 1997). The total loss also affects the market at different economic levels. It affects the farm (individual producer) as explained above, but also the sector (joint livestock farmers) which face a loss if the market price does not adjust itself. It also affects the processing industry with services and trade, the consumer due to higher prices and lower product quality, and the national economy due to inefficient use of resources (Dijkhuzien, 1992; McInerney, 1996). Due to diseases, additional resources are required that could have been employed otherwise, such as labor and imported feedstuff (Dijkhuzien, 1992). Losses caused by livestock diseases can be categorized into two significant groups: direct and indirect. Direct losses are usually at input level with visible losses such as deaths or abortion. Or invisible losses when diseases reduce the efficiency of the production process through reduced fertility, reduced feed conversion, and at an output level with lowered milk yield, and reduced milk quality due to mastitis for example (Chi et al., 2002). Diseases also cause indirect losses through additional costs, e.g., veterinary treatment, drugs, vaccines, quarantine, or to treat ill cases. It also includes sub-optimal exploitation of otherwise available resources, e.g., revenue is forgone, denied access to the better market, or use of suboptimal production technology (Rushton, 2009).

The total economic cost (C) of a disease is the sum of the production losses (L) (both indirect and direct), and eventual control expenditures (E), which are the extra input needed to limit losses, and it will differ between production system, disease, region, and country (Dijkhuzien, 1992; McInerney, Howe & Schepers, 1992). There is a substitution relationship between total loss and control expenditures and, for example, higher treatment and prevention expenditures result in lower losses (McInerney, 1996). The relationship is also likely to be non-linear and some combinations of L and E sum to a lower C, than others. The curve is assumed to slope downwards with a diminishing return to expenditures; for each dollar spent on expenditures, additional return in reduced losses becomes gradually reduced. By finding the optimal combination of these two components (e.g., try to reduce disease costs to a minimum), it is possible to minimize the total economic cost for the disease (Bennett, 1992).

3.3 Theoretical summary

In order to develop a model for estimating the effect of animal health on production, the above-presented literature, and theoretical framework will be used as a basis. The theoretical framework applied in this study clarifies the importance for firms to understand the production process. At the most fundamental level, firms must be as efficient as possible when transforming their inputs into outputs (Allen et al., 2013). The production function describes the technical relationships converting inputs into an output, and if there is a disturbance in the process, efficiency will most likely be reduced (Pindyck & Rubinfeld, 2009).

For agricultural producers, several inputs are required in order to produce an output, such as milk. For dairy producers, most of the revenue comes from sold milk, and the costs are both controllable and not. Buildings, machinery, and land are often referred to as fixed inputs, and these will not be changed over the analysis period (e.g., McInerney, 1991; McInerney, Howe

diminishing marginal return to the inputs, and when the marginal product of input increases with increased use of the other input (Kleyn et al., 2017). The function was, however, not developed based on any knowledge of engineering, technology or management of the production process, and it has been criticized for its lack of foundation (Mishra, 2010). Despite this, the function has advantageous mathematical properties and can provide a relatively accurate description of the economy. The function is often used for the fact that it is linear in the parameters and ordinary least square (OLS) can be used to estimate the variables (Green, 2012). By taking the natural logarithms on both sides of the equation, Cobb–Douglas function form can be estimated as a linear relationship using the following expression:

$$\ln(Y)=\ln(A)+ \alpha_1\ln(X_1)+ \alpha_2\ln(X_2)+ \ldots\alpha_n\ln(X_n) \quad (4)$$

4.4.2 Estimation of production function: Transcendental logarithmic

The transcendental logarithmic production function, also called translog function, was proposed by Christensen, Jorgenson, and Lau (1971, 1973). The translog function is an attractive, flexible function with both linear and quadratic terms and the ability to use more than two-factor inputs (Christensen et al., 1973). The two-input translog production function can be written in terms of logarithms as follows equation (5) and re-written as equation (6):

$$\ln(Y)=\ln(A)+ \alpha_1\ln(X_1)+ \alpha_2\ln(X_2)+ \chi\ln^2(X_1/X_2) \quad (5)$$

$$\ln(Y)=\ln(A)+ \alpha_1\ln(X_1)+ \alpha_2\ln(X_2)+ \alpha_{11}\ln(X_1)\ln(X_1)+ \alpha_{22}\ln(X_2)\ln(X_2)+ \alpha_{12}\ln(X_1)\ln(X_2) \quad (6)$$

The translog function is usually the preferred choice for most researchers due to the presence of quadratic terms which allows for nonlinear relationships between the output and inputs and due to its flexibility compared to other forms. Another important feature that characterizes a translog function is that it has no restrictions on substitution elasticity between production factors and is, therefore, more flexible and less restrictive than the Cobb-Douglas (Christensen et al., 1973). Cobb-Douglas is, in general, a specific case of the translog function imposing additivity and homogeneity by restrictions. The interaction variables in the translog function consist of both first derivate, second own-derivate, and second cross-derivate. If the interaction variables were significantly adding something to the model, they need to be included, otherwise, they should be removed (Djurfeldt & Barmark, 2009). If the variables do not contribute significantly, the more basic Cobb-Douglas function should be used instead.

4.4.3 Regression analysis

The logarithmic mathematical form with both translog and Cobb-Douglas functions entails that they can be relatively easily predicted using a regression analysis estimated with ordinary least square, OLS (Djurfeldt, Larsson & Stjärnhagen, 2010). The purpose of a regression analysis is to find out how certain independent variables affect a specific dependent variable (Djurfeldt & Barmark, 2009). The analysis also shows how much of the variation in the dependent variable that can be explained by the independent variable. An OLS analysis requires that the dependent variable is quantitative while the independent variables can be both quantitative and binary, so called-dummy variables. The basic model follows:

$$y=\alpha+ \beta_1x_1+\ldots+ \beta_nx_n+ u \quad (7)$$

Where: y is the dependent variable, α is the constant, β is a regression coefficient, x is the independent variable, and u is the residual. The residual has an interesting interpretation and should not be taken as a measurement error. The residual must be constant and normal distributed in order to execute the regression analysis (Djurfeldt, Larsson & Stjärnhagen, 2010). Secondly, the residual consists of the sum of the observed, un-observed and causal factors (including any measurement errors) that determine the dependent variables, and which have not been included among the independent variables. Because of this, the residual consists of more than just statistical noise and even if the measurement errors are equal to zero, the residual can be greater than zero (Djurfeldt & Barmark, 2009).

To evaluate the results of the regression analysis, several values are studied which indicates how well the estimated values describe the data set. The R^2-value (explanation rate) is between 0 to 1 and illustrates how well the variation in the dependent variable can be explained by the variation in the independent variables (Djurfeldt, Larsson & Stjärnhagen, 2010). The P-value show how significant the variables are, and the probability that the result is random, and the risk of error is reduced. Significance levels are usually divided into three levels, 1%, 5% and 10%. The coefficients of the independent variables show how much they affect the dependent variable and can be both negative and positive. Furthermore, the results also show the standard error which measures how accurate the estimate of the dependent variable is (Djurfeldt & Barmark, 2009).

There are mainly four problems and sources of error that can happen when calculating a regression analysis: miss-specified models, uneven distribution (heteroscedasticity), co-variation between independent variables (multicollinearity) and a non-normal distributed residual (Djurfeldt, Larsson & Stjärnhagen, 2010). Multicollinearity is a problem that occurs when two or more independent variables correlate to each other to a greater extent than the dependent variable (Djurfeldt & Barmark, 2009). This causes the regression coefficients to be incorrectly estimated in the model. If strong multicollinearity exists, the affected variables should be excluded from the analysis. Heteroskedasticity means that the variance in the residual (error term) is not constant, which is that the spread is uneven. This can lead to a misstatement of the significance level and misinterpretation of the result (Djurfeldt, Larsson & Stjärnhagen, 2010). Lastly, deviation from the precondition that the residual must be normally distributed indicate that there is, in fact, a correlation between u and x or y. This means that a causal factor that affects y has not been included in the model and this is called a specification-error (Djurfeldt & Barmark, 2009).

4.4.4 Hypothesis test

In order to test if the increased complexity with the translog function is necessary, or if the simplicity of Cobb-Douglas is more accurate, Wald test was performed and the null hypothesis (H_0) was tested against the alternative (H_1). Rejection of the H_0 signifies that the translog function is the appropriate model, while failure to reject the null hypothesis implies that the Cobb-Douglas function is appropriate. The Wald test (also called Wald-Chi-Squared Test) can be used to test if explanatory variables in a model are significant or not, meaning they add something to the model (Gregory & Veall, 1984). If Wald test shows that the parameters for the variables are zero, it suggests that the variables can be removed without harming the model and H_0 is accepted (Djurfeldt & Barmark, 2009).

4.5 Quality criteria for quantitative research

To achieve quality in quantitative research, there are several research criteria that must be met. If these criteria are not fulfilled, the results and the credibility of the study may be questioned.

4.5.1 Reliability

Reliability is a quality measure that concerns questions about the trustworthiness, consistency, and steadiness of measurements, i.e., whether results be the same if the survey is repeated (Bryman & Bell, 2015). Reliability also depends on the trustworthiness of the used data sources. Stability is essential to assure reliability and researchers must ask the question: have the results been stable over time. Data for this study is collected from sources which are considered to be accurate and reliable, and all variables are tested for heteroscedasticity and multicollinearity to avoid incorrect correlations and wrongful conclusions. The literature on which this study is based on consists of published articles from scientific journals and business administration course literature, which is sufficiently trustworthy and reliable to use for this study.

4.5.2 Validity

One of the most essential quality criteria is validity which concerns whether designed indicators measure what is expected to be measured, i.e., if the use of the invSCC variable measures animal health for dairy cows. Validity is also about the relevance of collected data for the given problem and the measuring instruments ability to measure what it intends to measure (Bryman & Bell, 2015). In order for the study to be as valid as possible, it is essential to use the correct measurement methods and measure what it intends to measure. Accordingly, in order for data to valid, the data collecting process needs to be performed correctly and the data need to be entered correctly in SPSS or STATA. Good secondary sources and source criticism may increase validity. There are different types of validity; internal validity which occurs if the conclusions are credible and are bound to the moment when the study was conducted (Bryman & Bell, 2015). The internal validity can be increased if all external factors that may affect the study are reduced, which in most cases are impossible. There is also construct validity which means that the concepts used when conducting the study are well defined. In this type of validity, the agreement is required on the operationalized forms of a construct and clarifying what we mean when we use the construct (Cohen, Manion & Morrison, 2011). Lastly, there is external validity, also called generalizability or transferability, which refers to what degree the results can be generalized or transferred to other contexts or settings (Bryman & Bell, 2015). With other words; transferability shows if the findings have applicability in another context. The quantitative methodology aims to draw generalized conclusions for an entire population by means of a selection, therefore, compliance of this criteria is crucial for the credibility of the study.

4.5.3 Replicability

The confirmation of research findings through replication by other researchers is an essential part of the scientific methodology, and it can serve as an excellent complement in quality assurance of research (Bryman & Bell, 2015). Replication studies are a natural way to ensure the reliability and validity of earlier results and a quantitative study should be able to be performed several times with the same results. Replication is also a way to minimize the impact that the researcher’s skepticism and lack of objectivity contribute to (Cumming 2008; Verhagen & Wagenmakers, 2014). If the replication is not possible, or the results from a replication study differs from the original results, the validity should be questioned.

5 Results

As stated in 4.4, in order to determine the production function, two different models were chosen. The results in Table 1 illustrate a summary of the findings from the different models. The variables used in the analyzes are explained in detail in the appendix. Model 1 and Model 2 are two different Cobb-Douglas production functions. The difference between Model 1 and 2 is the control variable (partSH). The control variable did contribute significantly to the model and needed to be included. Model 3 is the translog production function. The results from the Wald's test showed that the interacting variables in the translog function did not significantly adding anything to the model, and could, therefore, be removed, indicating Cobb-Douglas is the appropriate model. However, the control variable did contribute and consequently needed to be included in the final Cobb-Douglas model (Model 2). Further explanations of the results and the variables are found in the article manuscript.

Table 1. Summary results of the regression models.

Variables	**Model 1.**	**Model 2.**	**Model 3.**
lnTC	-0.103**	-0.082**	-0.1.33
lnn	-0.027*	0.023	-1.057
lninvSCC	0.108**	0.100**	-0.420
partSH		0.112***	0.118***
lnTC x lnTC			0.099
lnn x lnn			0.001
lninvSCC x lninvSCC			0.045
lnTC x lnn			0.185*
lnTC x lninvSCC			0.152
lnn x lninvSCC			-0.015
Constant	10.368***	10.162***	15.148
R-sq.	0.167	0.307	0.339

***Statistically significant at 1%. **Statistically significant at 5%. *Statistically significant at 10%

6 Discussion

In this chapter, the results and the quality criteria for this study are discussed. Furthermore, the study's empirical contribution to the Swedish dairy industry is presented. Further discussion about the results as well as suggestions for future studies can be found in the article manuscript.

6.1 Result discussion

In this study, I investigated how animal health affects the production by presenting a general model that can be used to estimate the effect of animal health on production. The theoretical framework adopted in this study was based on the fundamental assumption that any business strives to maximize their utility, therefore, controlling the costs and maintaining the efficiency are crucial factors to become profitable in modern farming. It is in the production process that companies create their values and any type of disturbance in this process may lower the amount of output, by increasing the inputs needed or reducing the efficiency of the inputs (Pindyck & Rubinfeld, 2009). In accordance with, e.g., Bennett (2003), McInerney (1996) and Dijkhuzien (1992), reduced animal health due to diseases such as elevated SCC were in this study considered to cause a disturbance in the production function, which prevents outputs from being produced at an average level.

As stated in chapter two, the Swedish dairy industry has undergone significant structural changes over the last three decades, and remaining producers need to optimize their production and their technical efficiency in order to survive. However, the Swedish dairy industry is considered to be the most valuable sector in Swedish agriculture of the products produced for further trading (Bergh, 2018; SCB, 2018). This illustrates the value of remaining producers surviving in the long run. Bennett (2003) argues that the prevention of animal diseases and improving animal health may be critical elements in the development of competitive livestock production systems, I could not agree more. Mastitis costs the Swedish dairy industry nearly 192 million SEK a year and is also the main reason for antibiotic treatments in Swedish livestock production, which illustrates the severity of the disease (Nielsen et al., 2010). Mastitis also results in economic losses to the producers, reduced animal health for the cow and causes problems with the raw milk quality for the dairy processor (Bennett et al., 1999; Carlén, Strandberg & Roth, 2004; Halasa et al., 2009). Overall, reduced animal health due to elevated BTSCC and mastitis affects all the actors on the food chain for dairy products. For an industry that is already exposed to competition and slim economic margins, acute and preventive work on udder health becomes essential issues that the producers face in their daily practice of becoming profitable. Results from previous studies also show that there is a growing concern within the society for animal health which should not be ignored (e.g., D'Silva, 2009; Hansson & Lagerkvist, 2012; Lagerkvist, Hansson, Hess & Hoffman, 2011; Lusk, Nordwood & Prickett, 2007).

For this study, I assumed that a farmer who knows that mastitis causes production inefficiencies, additional costs, and suffering to the cow, can be motivated to act in the prevention of mastitis, even if the BTSCC is not close to a possible penalty level. Based on this assumption, I proposed a model which considered that farmers manage their mastitis preventive strategies as investments in animal health. The investment is seen as an asset in production and modelled as a production input variable. Similar to how firms make certain investment decisions to benefit from the productive capacity of labor, machinery, buildings et cetera, I assumed that farmers make decisions to benefit from the investment in animal health by reducing the BTSCC and mastitis.

Improving animal health for dairy cows will lead to a higher milk yield per producer which is equal to more milk in the food chain, less milk sorted out due to ban on the sale of milk from cows with mastitis (which lower the proportion of emission/ kilo milk produced), and reduced use of antibiotics which is highly relevant today. It may also generate milk with better quality which enables dairy product development. For the producers, the economic implications of improved animal health by reducing mastitis will lead to lower costs for sick cows, less labor spent on sick cows, higher profit margins, and hopefully, more dairy producers or at least not fewer. For the cows, improved animal health could mean a longer life expectancy since mastitis and high SCC are the most common cause for culling among Swedish dairy cows (Nielsen, 2009). Also, healthier cows have a value for the food sector since poor animal welfare, have a negative externality on food production, and this is an essential aspect for the producers to consider (Ingenbleek & Immink, 2011; Lusk, Nordwood & Prickett, 2007). Overall, healthier cows will help develop a more sustainable and stronger Swedish dairy sector.

To my knowledge, this is the first time that investments in animal health have been seen as an individual production factor, which makes the analysis unique. From the production function it is possible to estimate how inputs can be distributed to maximize output, and since all companies are expected to strive for profit maximization, companies are expected to streamline production as far as possible (Allen et al., 2013). Each dairy farm has a unique production function, which applies to the available technology, and the results of this study provide estimated coefficients for the input variables. Based on the concept presented in the theoretical framework stating that a disturbance in the production process causes a downward shift in the production function (Allen et al., 2013; Pindyck & Rubinfeld, 2009), investments in animal health leads to the opposite. From the results presented in Model 2 (see Table 1), the following regression can be applied to the dairy farms' production (equation 8) and re-written to its original Cobb-Douglas form (equation 9):

$$\ln Y = 10.162 + (\ln TC \text{ x } -0.082) + (\ln n \text{ x } 0.023) + (\ln invSCC \text{ x } 0.1) + (partSH \text{ x } 0.112) \quad (8)$$

$$Y = 10.162 TC^{0.082} n^{0.023} 1/SCC^{0.1} partSH^{0.112} \quad (9)$$

From this equation, calculations can easily be made to illustrate how investments in improved animal health increase the milk yield. The partial output elasticity for the animal health variable 1/SCC is 0.1, i.e., if a dairy producer invests in improving animal health by 1%, i.e., lowering the BTSCC with 1%, this generates 0.1% kilos ECM more in output. If the producer improves the health by 10%, it will generate 1% more in output. The average dairy farm in the data sample (see Table 1 in the appendix) produces 10 441 kilos ECM/year and has a mean BTSCC 241 028/ml. If the producer, in this case, invests in improving animal health by lowering the BTSCC with 10% (24 102.8), it will generate 104.41 kilos ECM more. From the results, the producer can see the net effect of investing in animal health and how the revenues are expected to increase if the BTSCC is reduced. However, the economic impact of the investments on the individual producers depends on which payment system the dairy processor has. Eventual premiums in the settlement price may have additional benefits to investments in animal health. For a Swedish dairy producer who delivers milk to Arla Foods, an investment in animal health, which reduces BTSCC from 200 001 to less than 200 000, will generate +1% of the settlement price. This together with the additional output produced due to the investment, gives increased revenue, as exemplified above.

The results from this study can be used as the foundation for evidence-based counseling aimed to help farmers become more efficient with the management of mastitis. The tool developed in this thesis can help improve decision making, therefore, the tool developed in this thesis was more simple and straightforward. On the basis of the results from this study, Swedish dairy producers can become aware of the importance of lowering the BTSCC in order to improve animal health and the profitability of the farm. For the Swedish dairy industry, improving animal health entails several positive aspects in addition to being seen as a step towards creating a more sustainable food chain. The variable 1/SCC represent the revenue side in the production function, and the investments of improving animal health (decrease BTSCC) will represent the cost side. If the farmer invests in lowering the BTSCC, this will have a dynamic effect on the other factors as well. Advisory organizations such as Växa Sverige can help the dairy producers determine whether a 10% investment in improved animal health is worth the costs that are added.

The Cobb-Douglas function has several restrictions, as stated earlier, such as; all inputs are essential for production, and no output can be produced without using at least some of each input (Kleyn et al., 2017; Mishra, 2010). This is consistent with the results of this study. The proxy variable for animal health is one of the most important coefficients in the function, significantly more important than the number of cows (n) and TC. Investing in animal health is, therefore, an essential part of milk production. Further discussion regarding the results can be found in the article manuscript.

6.2 Method discussion

In one way or another, there will always be threats to the quality of all types of studies. In this study, the explanation rate (R-squared) of the regression model is relatively low (around 30%, see Table 1), which I am aware of. However, this study is based on existing data, which means that the rate cannot be improved. It may be a risk that data has been entered incorrectly in SPSS, or that imprecisions occur when data has been merged into new variables. This may have affected the result and lead to errors. To prevent this, the data has been analyzed both using SPSS and with STATA in consultation with both supervisor and assistant supervisor which reduced the risk of mistakes.

Modelling the inverse value of a disease as an input variable requires that data is reliable. For example, Bennett (2003) argues that estimates of economic effects due to animal diseases are only as good as the data upon which they are based on, which requires that data collection and analyses will be executed with high precision. The designed indicator (1/SCC) is considered to measure animal health for dairy cows. The variable was developed based on previous literature on udder health and mastitis, and the results of this study imply that there is a significant economic value for investing in animal health. Furthermore, this study is based on secondary data, which usually has a higher quality than primary data (Bryman & Bell 2013). This is because the sample can represent the total population better, as data has been analyzed and processed earlier. By using secondary data, more time was spent on data processing and analyzes, which increases the certainty that the results are valid.

The sample for this study was as representative as possible; however, the representativeness may be questioned, this is discussed in further depth in the article manuscript. The new GDPR slowed down the data selection and the sample was prevented from being completely random. All of the farm owners that could provide consent before the start-up date of this study were included in the data set. But the dairy farms that did not leave the consent in time were not included which makes the sample non-random. Although it was technically possible to access data from the entire population, this was limited by the time aspect. Due to the non-random selection, sampling error may exist, and this may limit the generalization of the results.

As stated in Chapter 4, the translog production function is usually the preferred choice for most researchers, but the increased complexity with the translog function was not necessary for this study. The results from the Walds test showed that the interacting variables were equal to zero, indicating that the variables can be removed without any harm to the model fit since the variables are not contributing significantly. Choosing the most accurate method increases validity. Data for this study were collected from sources which are considered to be accurate and reliable. The models were evaluated for heteroscedasticity, but there were no indications that there is a problem with heteroscedasticity in neither of one (see pages 38-40). Furthermore, the models were tested for multicollinearity, and there were no indications that there is a problem with multicollinearity in neither of Model 1 or Model 2. For Model 3 multicollinearity exists as a part of the translog model since the high correlation between the interacting variables results in an inability to estimate the coefficients precisely.

The model developed in this study can be generalized to other countries with similar production systems, especially within the European Union where the maximum BTSCC is set at 400 000 (Council Directive 92/46/EEC). The model can also be generalized to other livestock-production systems such as cattle production, pork or others, but in such instances, the animal health variable needs to be adjusted for diseases of these production animals. This model also allows for replication which strengthens the validity of the results.

Other methods could have been used as complement to this study, such as in-depth interviews with dairy farm owners or veterinarian, but in order to maintain objectivity, this was excluded. The individual farmers have been completely anonymous which reduces the risk of damaging the privacy of respondents, no ethical issues have arisen.

7 Conclusions

In his thesis, a microeconomic framework was established for developing a model to investigate how animal health affects the production for Swedish dairy producers. By modelling the effect of animal health as an input variable, it shows how the production function can change when animal health is improved, which will affect the output produced. The modelling also concretizes the economic value of improved animal health, and investment in animal health is seen as an asset in production.

The Swedish dairy industry is considered the most valuable sector in Swedish agriculture of the products that are produced for further trade. Therefore, it is highly relevant that the remaining companies maintain profitability.

The findings from this study showed that investments in animal health play a significant role in the production process of dairy farming. Also, improving udder health can play a significant role in achieving an efficient and economically rewarding milk production. This study contributes to the existing literature by presenting a new way of modelling the effect of animal health, compared to what has been previously done. Seeing animal health as a production factor has not been previously done. The model presented in this study can be used as a simple tool for evidence-based counseling in order to help dairy farms become more efficient with the management of mastitis, by lowering the BTSCC and improving animal health and the profitability of the farm. Improving animal health entails several positive aspects in addition to being seen as a step towards creating a more sustainable food chain.

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Appendix. Article manuscript

Modelling animal health as a production factor in dairy production - a case of Swedish dairy agriculture

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Livestock diseases are an undesirable contribution to the production process. Diseases lower the producer's profit margins by reducing animal health and causing unnecessary suffering to the animals. For dairy production, mastitis is the most severe disease and causes both reduced animal health, increased costs, and reduced milk yield. The purpose of this study was to investigate how animal health affects the production by presenting a general model that can be used to estimate the effect of animal health on production. Empirical data consisted of farm-level accounting data of Swedish dairy producers combined with biological facts of the dairy herds. A multiple regression analysis was used to investigate how animal health affects the production. Results show that animal health plays a significant role in the production process of dairy farming. The study illustrates how the production function will statistically change when animal health is improved. The model developed in this study can be a useful tool for evidence-based counseling in order to help dairy farms become more efficient with the management of mastitis. The developed model can also be generalized and used for other livestock production systems to investigate how animal health affects production.

Introduction

Diseases in livestock play a crucial role in modern farming and affects the production in several different ways by reducing the efficiency and causing unnecessary suffering to the animals (e.g., Bennett, 2003; Chi, VanLeeuwen, Weersink & Keefe, 2002; Dijkhuzien, 1992; McInerney, 1991; McInerney, Howe & Schepers, 1992). From a microeconomic perspective, livestock diseases represent an undesirable effect in the process of converting production inputs to outputs by destroying the basic resources and thereby lowering profit margins (Chi et al., 2002; Hansson, Szczensa-Rundberg & Nielsen, 2010). Because of diseases, losses arise to the producers through lower product quality and/or lower product level. There are also direct costs, e.g., veterinary costs, medicine, increased culling et cetera, and the total economic cost may vary between production systems, diseases, regions, and countries (McInerney, 1996; Dijkhuzien, 1992).

Numerous different analytical methods have been used to estimate losses and disease costs. Several studies have used costs-benefits analysis to evaluate different preventive strategies and control programs (e.g., Groenendaal, Zagmutt, Patton & Wells, 2016; Valle et al., 2005; Truong et al., 2018), some have designed stochastic dynamic models (Niemi et al., 2017; Schoenbaum & Disney, 2003), budget models (e.g., Holtkamp et al., 2013, Chi et al., 2002, Shulz & Tonsor, 2015), dynamic bioeconomic models or different simulation models (e.g., Blake, Sinclair & Sugiyarto, 2003; Cao, Klijn & Gleeson, 2003; McArt, Nydam & Overton, 2015; Rushton, 2009). The common denominator is, however, that impaired animal health cause direct losses with visible and invisible signs, e.g., abortion, deaths, reduced efficiency through reduced fertility, feed conversation, lower yields, and reduced product quality.

For dairy production, mastitis represents one aspect of animal health and the disease is considered to be the most common and costly production disease in dairy herds worldwide (e.g., Carlén, Strandberg & Roth, 2004; Halasa et al., 2007; Holland, Hadrich & Lombard, 2015; Seegers et al., 2003). While mastitis usually is treatable, economic losses are substantial. The disease is associated with reduced milk yield but also reductions in output price due to penalties for high somatic cell count (SCC). Mastitis is also associated to veterinary and treatment costs, additional labor and increased culling rate (e.g., Bar et al., 2008; Hagnestam-Nielsen & Østergaard, 2009; Huijps, Lam, & Hogeveen, 2008). Mastitis, therefore, interferes with the economic outcomes of dairy farms (Hansson, Szczensa-Rundberg & Nielsen, 2010). Reducing the frequency of mastitis is necessary in order to develop competitive dairy production systems, but improved animal health and minimizing the use of antibiotics are also essential arguments (Bennett, 2003). Mastitis can be recognized by increasing SCC which become present in rising numbers as the immune system responds to a mastitis-causing pathogen (Huijps & Hogeveen, 2007). In most countries in the European Union, there is a maximum limit on the bulk tank SCC (BTSCC) allowed in milk produced for human consumption, followed by penalties and premiums which may have a significant impact on the milk revenue for the producers (Council Directive 92/46/EEC).

Previous calculations of the economic loss of mastitis show significant variations in the results between different studies. Economic losses differ between €53 to €120 per cow and case of mastitis depending on the level of BTSCC and the main component of loss is reduction in milk yield which is estimated even higher for subclinical mastitis (SCM) (e.g., Bar et al., 2008; Halasa et al., 2007; Huijps, Lam & Hogeveen, 2008; Kossaibati & Esslemont, 1997; Seegers et al., 2003; Østergaard et al., 2005; Yalcin, 2000). Cost per case of mastitis has been estimated to vary between €278 and $444 (Hagnestam-Nielsen and Østergaard, 2009; Rollin, Dhuyvetter & Overton, 2015). Past literature regarding the effect on the milk yield show that rising SCC have a significant negative effect on the milk yield (e.g., Halasa et al., 2009; Hagnestam-Nielsen & Østergaard, 2009; Hagnestam et al., 2007; Korhonen & Kaartinen, 1995). The yield is reduced with 4% when the level rises from 250 000-500 000, 7% when rises to 700 000 and close to 20% when exceeding 1000 000, this is equal to 200-750 kilos energy corrected milk (ECM)/cow and year.

Knowing the consequences of elevated SCC and mastitis, farmers are considered actively working with preventive measures. These measures can be seen as direct investments in animal health. Similar to how firms make certain investment decisions to benefit from the productive capacity of for example labor or capital, I assume that farmers make decisions to benefit from the investment in animal health. From an economic perspective, animal health could be seen as a production factor just as labor or capital, all of which are crucial for a company to be able to produce an output. Investments in animal health will, therefore, increase the output level.

The purpose of this study was to investigate how animal health affects the production by presenting a general model that can be used to estimate the effect of animal health on production. In this study, the absence of mastitis will represent animal health, in order to provide estimates that can support strategic decision-making and motivate and dimension preventive work against poor udder health and mastitis. By modelling the effect of animal health as an input variable, it illustrates how the production can change when animal health is improved, which will affect the output produced. The model developed in this study is meant to be used in practice by farmers, veterinarians, and other advisors, or form the basis for future research. This study contributes to the existing literature by presenting a new way of modelling the effect of animal health, compared to what has been previously done. Seeing animal health as a production factor has not been previously done. By doing so, the economic value of improved animal health are concretized, and investments in animal health are seen as an asset in production.

In relation to this study, previous research has used other methods when estimating the effect of animal health. Only a few studies (e.g., Bennett, 1992, 2003; Chi et al., 2002; Yalcin et al., 1999; Yalcin, 2000) have used production functions when analyzing the direct effect of livestock diseases, as suggested by McInerney (1991). By not using production functions when estimating the impact from diseases, the results may be incorrect and essential conclusions may be overlooked. The results from earlier published literature regarding mastitis vary significantly and estimates from, e.g., simulation models are higher than estimates calculated from other methods which may question the validity of the analysis methods (e.g., Bar et al., 2008; Hagnestam-Nielsen & Østergaard, 2009). Variation in the results of previous estimates may also be explained by different studies using different cost categories in their calculations (e.g., Bennett et al., 1999; Halasa et al., 2007; Huijips et al., 2008; Rollin et al., 2015). Other reasons for the variation seem to be the origin of data or the definition of mastitis (Nielsen, 2009). For this reason, there is a need for a general model to estimate the effect of animal health. This is essential as it becomes difficult to replicate the studies when no general models have been designed and used. Estimating the effect of animal health on the production can both help to analyze the situation, limit the losses and determine the extent of the loss to be avoided, in order to improve the profitability of the farm. The findings from this study can serve as a basis for future research on the effect of animal health. The results can also be used for evidence-based counseling aimed to help farmers become more efficient with the management of mastitis. Based on the results of this study, Swedish dairy producers can become aware of the importance of lowering the BTSCC in order to improve the profitability of the farm by improving animal health.

Material and methods

Data sources

Data was provided from Växa Sverige and consisted of information obtained from different sources; i) individual farmers, ii) production animal associations, iii) veterinarians, iv) slaughter companies, and v) a milk laboratory. Sweden has currently 3600 dairy producers, and 2557 are members of Växa Sverige (Bergh, 2018; Växa, 2018). The average farm among Växa Sveriges members has 89.1 dairy cows and producing 10175 kilos energy corrected milk (ECM)/cow and year, with a geometric mean of all herds BTSCC at 188. Compared to the average Swedish dairy producer, who has 91 cows and producing 8900 kilos ECM.

The individual producers in the sample were selected non-randomly, and the sample could have been greater. However, the new EU General Data Protection Regulation (GDPR) came into force on May 25th and limited the selection size since the regulation demand permission for businesses to store personal data (EU 2016/679). For Växa Sverige, GDPR meant that each farmer needed to give consent to store their data and to match the datasets (farm accounting data and biological data). Due to the new GDPR, the data selection was prevented from being completely random, and 99 consents were collected until the start of this study.

Table 1 present the descriptive statistics on the input and output variables used in the empirical analysis. The standard deviations are rather large, indicating a large amount of variation in the sample, as shown by the minimum and maximum values of the normal distribution in Table 1. The average farm in the sample has 124.7 cows and producing 10441 kilos ECM/cow and year which is slightly higher than the average Swedish producer (P=0.007) and the average member of Växa Sverige (P=0.001). The average BTSCC is 241 compared to 188 for the average member of Växa Sverige (P=0.001). The difference is significant, but there could be a risk of selection bias.

Table 1: Descriptive statistics: input-output variables on participating dairy farms (n=99).

Variables	**Mean**	**St. dev.**	**Min**	**Max**
Output				
Kilos ECM (output)	10441	955.1	8061	13071
Inputs				
Number of cows (n)	124.69	100.10	22.30	536.50
Total costs (TC, Swedish krona)	572.93	124.96	364.44	1040.40
Bull tank somatic cell count (BTSCC)	241.03	54.51	96.83	398.3
Inverse SCC (invSCC)	0.0043	0.0010	0.0025	0.0103
Proportion SH (partSH)	0.431	0.312	0.00	1.00

Farm accounting data.

To construct the input variables needed to estimate the production function, detailed farm level accounting data were used. Each of the 99 farms was represented by one year of economic outcomes and deflated by national consumer price index to 2017(=100) as a base (SCB, 2018). The dataset consisted of direct costs, which are directly related to dairy production and not carried by other business areas. In this category, seed, manure, fertilizer, feed, replacement, counseling, semen, contract work, and veterinarian are included. Though, this may vary depending on how the farmers reported the events. Furthermore, the data set included labor costs and cost for concentrates. Moreover, the data set also included indirect costs, involving leasehold, insurances, lawyer, diesel and other common costs related to more business areas than milk production only. Since the opportunity costs for, for example, leasehold, was unknown, and the costs categories include more than milk production costs, the indirect costs were not included in the analysis. This in order to limit errors in the analysis.

The farm-level accounting data were supplemented with farm-specific biological facts about the herds. Total production outputs, as recorded through the monthly test-day recordings, were aggregated into a single measure of produced milk (ECM/cow and year). Furthermore, breed compositions, number of cows, and average BTSCC were included as input variables. The data regarding BTSCC was compiled over 12 months and mean value per producer was used. Furthermore, data included mainly three groups of different breeds; Swedish Red (SR) geometric mean 0.515, Swedish Holstein (SH) 0.433 and one group with other breeds, 0.052 The distribution between the breeds slightly differ from the Swedish average where SH is the most common and represent 0.55 of the entire population (P=0.001) (Bergh, 2018). The biological data was gathered and compiled for three years but were matched against the accounting year (2017) for each farm.

Modelling animal health

Diseases affect the production in several ways as stated in the introduction, representing an undesirable effect in the production process. The somatic cell count is an indicator of potential mastitis, and it is associated with reduced animal health by causing suffering to the cow. The costs and yield losses associated to the disease, and the milk payment system involving premiums and penalties depending on the BTSCC levels, affects the extent to which the farmer invests in preventive care to increase animal health. Assuming farmers want to work efficiently when transforming production inputs to output, investments in animal health are made, but to what degree is not considered in this study. To design the animal health variable, the data for BTSCC was transformed into its inverse value to illustrate that the producer has invested in animal health. The inverse value indicates low BTSCC, and this was equated with improved animal health and set as a proxy variable. The variable 1/SCC was then used as an input production factor representing the revenue side in the production function. The model considers that the BTSCC may affect the other input variables in the production function as well as the output and given everything else alike, investments in animal health, by improving udder health in different ways which lower the BTSCC, will affect the output. In this case, the animal health production function is formed to measure how the output is the resulting benefit from investments in animal health (decreased prevalence of mastitis and lower the BTSCC), and the function can, therefore, be termed a benefit function, in accordance with Bennett (1992, 2003).

Methods for estimating the production function

The analytical framework applied in this study builds on the literature clarifying the importance of using production functions in estimating the effect of animal health. The equations presented below are described as log-linear functions since both the dependent and the independent variables have been log-transformed. Therefore, the functions can be relatively easily predicted using regression analysis. The analysis consisted of three steps with two different methods; Cobb-Douglas and translog production function. If the choice of the functional form is incorrect, the results may be biased. The most commonly used production function is the Cobb-Douglas, which has advantageous mathematical properties and can demonstrate the technical relationship between two or more input factors and the output, but it has been criticized for its simplicity (Kleyn et al., 2017; Mishra, 2010). The second model is the translog function, which is considered to be more flexible compared to the Cobb-Douglas function (Christiansen, Jorgenson & Lau, 1971, 1973). Translog functions are used to examine input substitution separability and aggregation. By adding interaction terms (by joint estimates) to the function, a greater understanding of the relationship between explanatory variables and explained variable can be achieved. As a starting point for analysis, a basic Cobb-Douglas function was specified in the form of:

$$\ln(Y)=\ln(A)+\ln(TC)+\ln(n)+\ln(invSCC) \quad (1)$$

Where ln(Y) is the logarithm of output milk (kilo/ECM) that the farmers produce in a year, and A is the intercept (constant). The production input variables were ln(TC), the logarithm of total costs for dairy production, which consists of the direct costs presented above, added together with labor costs and costs for concentrates. The variable ln(n) consists of the logarithm of numbers of cows and ln(invSCC) is the proxy variable used to illustrating investments in animal health as an input variable. The Cobb-Douglas was estimated based on OLS-technique.

As a second step, the Cobb-Douglas function in Model 1 was developed to include a control variable for the breed composition of the herd; partSH. The Holstein ratio was introduced as a control variable, indicating the proportion of Holstein cows in the herd since cows of the Holstein breed are more prone to get mastitis (Hagnestam-Nielsen & Østergaard, 2009; Halasa et al., 2007; Nielsen et al., 2010). The control variable was used to exclude that a relationship between the variables only exists as a causal effect and the interesting relationship was therefore streamlined. The mathematical structure of the function is displayed in the following equation:

$$\ln(Y)=\ln(A)+\ln(TC)+\ln(n)+\ln(invSCC)+partSH \quad (2)$$

Lastly, a three-input translog production function was estimated by extending Model 2. The translog function has both linear and quadratic terms and the ability to use more than two-factor inputs. Six interaction variables were included to see if the interaction is present with the possibility of substitution and if this in any way affects the results. This function consists of both first derivates ln(TC), ln(n), ln(invSCC), own second derivates ln(TC)ln(TC), ln(n)ln(n), ln(invSCC)ln(invSCC) and cross-section derivates ln(TC)ln(n), ln(TC)ln(invSCC), ln(n)ln(invSCC). Lastly, the function also included the same control variable as Model 2. The mathematical structure of Model 3 is displayed in the following equation:

$$\ln Y = \ln(A) + \ln(TC) + \ln(n) + \ln(invSCC) + \ln(TC)\ln(TC) + \ln(n)\ln(n) + \ln(invSCC)\ln(invSCC) + \ln(TC)\ln(n) + \ln(TC)\ln(invSCC) + \ln(n)\ln(invSCC) + partSH \quad (3)$$

The input variables have been selected based on the ground that they reflected general production factors and based on what previous studies have used when estimating production functions for dairy farms (e.g., Ahmad & Bravo-Ureta, 1995; Alvarez & Arias, 2004; Saha & Jain, 2004). These studies have used Cobb-Douglas and translog functions to estimate technical efficiency for dairy farms. Input variables have been cows, concentrates, buildings, veterinary expenses, labor (both hired and unpaid family labor), crop expenses such as fertilizer, seed, machinery, and roughage expenses incurred in producing on the farm. Data for indirect costs could have been used in the analysis to include costs for machinery and other joint business costs. Due to the uncertainty about eventual non-consistent accounting, the total costs only consisted of direct costs, and indirect costs were excluded in order not to avoid any measurement errors and bias to the results. The choice of variables, therefore, means that the analysis is done within the framework of fixed resources. The effect from cleaning the variables will be that only production from the cow stall is modelled, everything else is counted as given. In all three models, variables with $P<0.1$ were considered to be statistically significant.

Test for determining production function

In order to test if the increased complexity with the translog function is necessary, or if the simplicity of Cobb-Douglas is enough, Wald test was performed, and the null hypothesis (H_0) was tested against the alternative (H_1). Rejection of the H_0 signifies that the translog function is the appropriate model, while failure to reject the null hypothesis implies that the Cobb-Douglas function is appropriate. The Wald test (also called Wald-Chi-Squared Test) can be used to test if explanatory variables in a model are significant or not, meaning they add something to the model (Gregory & Veall, 1984). If Wald test shows that the parameters for the variables are zero, it suggests that the variables can be removed without harming the model and H_0 is accepted.

Results

The results from the regression analyzes are presented in Tables 3-5 below. The R-squared values were rather low for Model 1 (16.7%) but were almost doubled for Model 2 (30.7%), and Model 3 (33.9%). All of the models were evaluated for heteroscedasticity, but there were no indications that there is a problem with heteroscedasticity for neither of the models (Model 1 Ch^2 0.36, Prob> Chi^2 0.5469, Model 2 Chi^2 0.39, Prob> Chi^2 0.5317, and Model 3 Chi^2 0.18, Prob> Chi^2 0.6732). Furthermore, the models were tested for multicollinearity, and there were no indications of this for Model 1 **(**VIF between 1.015-1.160) or Model 2 (VIF between 1.030-1.173). For Model 3 multicollinearity exists as a part of the translog model because of the high correlation between the interacting variables, which results in an inability to estimate the coefficients precisely.

The results from the Walds test performed for Model 3 showed that the interacting variables were not significantly different from zero, indicating that the variables can be removed without any harm to the model fit since the variables are not contributing significantly. H_0 was accepted, and therefore, the Cobb-Douglas function was considered more suitable compared to the translog function for data analysis. The control variable partSH however, was contributing significantly and thus needed to be included in the regression.

In Model 1 (see Table 2), the coefficients for total costs (-0.103), and numbers of cows (-0.027) were significantly negatively associated with the dependent variable, which is in conflict with the logic of Cobb-Douglas functions. The animal health variable invSCC (0.108) was significantly positively associated with the dependent variable. For Model 3, total costs (-1.33) were negatively associated with the dependent variable in its first derivate and became positively associated in its own second derivate (0.099), however not statistically significantly. Numbers of cows (-1.057), and inverse SCC (-0.420) were both negatively associated in the first derivate and positively associated in their second derivate (0.001, 0.045), but not statistically significantly. The control variable partSH was significantly associated with the dependent variable at 1% level. Only one of the cross-section interaction variables were significantly positively associated with output (ln(TC)ln(n)=0.185), the other two were not significantly associated (ln(TC)ln(invSCC)=0.152), and ln(n)ln(invSCC)=-0.015).

Based on the results of the Walds test, Model 2 (presented in Table 3), was the most suitable model for investigating how animal health affects the production. Model 2 also estimated a Cobb-Douglas function but for this model a control variable was included, see Table 3. The results of Model 2 indicate that total costs (-0.82) still were significantly negatively associated with the dependent variable. Numbers of cows (0.023) became positive but not significantly associated with the output. The invSCC (0.100), and the control variable partSH (0.112) were significantly positively associated with the dependent variable. The model did not show significant support for omitted variables (F=0.45, Prob>F=0.71163), H_0 was accepted.

Table 2. Results from Model 1: Cobb-Douglas production function

Variables	Coef.	Std. Err.	P	[95% Conf.	Interval]
lnTC	-0.103	0.045	0.024	-0.193	-0.014
lnn	-0.027	0.182	0.075	-0.003	0.056
lninvSCC	0.108	0.038	0.005	0.033	0.182
Con	10.368	0.384	0.000	9.607	11.130
R-sq.	0.167				

Table 3. Results from Model 2: Cobb-Douglas production function including control variable

Variables	Coef.	Std. Err.	P	[95% Conf.	Interval]
lnTC	-0.082	0.042	0.053	-0.165	-0.001
lnn	0.023	0.014	0.102	-0.005	0.050
lninvSCC	0.100	0.035	0.005	0.032	0.169
partSH	0.112	0.026	0.000	0.061	0.163
Con	10.162	0.355	0.000	9.457	10.866
R-sq.	0.307				

Table 4. Results from Model 3: Translog production function including control variable.

Variables	Coef.	Std. Err.	P	[95% Conf.	Interval]
lnTC	-1.33	2.376	0.576	-6.0154	3.388
lnn	-1.057	0.882	0.234	-2.809	0.696
lninvSCC	-0.420	2.132	0.844	-4.657	3.816
partSH	0.118	0.029	0.000	0.061	0.174
lnTC x lnTC	0.099	0.162	0.542	-0.223	0.420
lnn x lnn	0.001	0.020	0.963	-0.039	0.041
lninvSCC x lninvSCC	0.045	0.125	0.719	-0.202	0.292
lnTC x lnn	0.185	0.102	0.072	-0.017	0.387
lnTC x lninvSCC	0.152	0.207	0.813	-0.258	0.562
lnn x lninvSCC	-0.015	0.065	0.463	-0.115	0.146
Con	15.148	11.503	0.191	-7.712	38.01
R-sq.	0.339				

Discussion

In this study, I investigated how animal health affects the dairy production by using the inverse value of SCC as an input variable in the production function. The results imply that there was a significant economic value for investing in animal health because the coefficient for invSCC was positive and statistically significant. The proxy variable for animal health is one of the most important coefficients in the function, significantly more important than the number of cows (n) and total costs (TC). Investing in animal health is, therefore, an essential part of milk production. This study contributes to the existing literature by presenting a new way of modelling the effect of animal health. By doing so, the economic value of improved animal health is concretized, and investments in animal health are seen as an asset in production.

One of the most critical factors influencing the costs of mastitis is production losses (Bar et al., 2008; Halasa et al., 2007; Hujips, Lam & Hogeveen, 2008). In accordance with the literature mentioned above, this study clearly shows that the presence of a disease (SCM) and reduced animal health results in output loss and additional input use. Consistent with the results from, e.g., Halasa et al. (2009), Hagnestam-Nielsen and Østergaard (2009), rising BTSCC has a significant negative effect on the milk yield and as stated in the introduction, impaired animal health cause direct losses, reduced efficiency and reduced product quality (e.g., Groenendaal et al., 2016; Holtkamp et al., 2013; Valle et al., 2005; Rushton, 2009). For an industry that is already exposed to competition and slim economic margins, acute, and preventive work on udder health becomes essential issues that the producers face in their daily practice of becoming profitable. In a global perspective, reduced animal health in dairy cows leads to extensive inefficiencies, including a higher proportion of emissions per kilos of milk produced. Hence improved animal health is an important sustainability aspect for dairy production.

Quantitative modelling of animal health is not an entirely new phenomenon. However, using a disease to design a production input variable is. For example, Bennett (1990, 2003) modelled production functions but placed a disease as increased costs to determine output loss. This illustrated how higher treatment and prevention expenditures resulted in lower losses, but the function did not highlight animal health as an individual variable. This study differs from the previous ones by providing a new way of modelling animal health as an individual production factor. In this case, a flexible and simple model is necessary to represent dairy production and investments in animal health. To my knowledge, no authors have emphasized the productive value of animal health, which makes the analysis unique.

The negative coefficients for the total costs (in Model 1 and 2 presented in Table 2 and 3) and the variable numbers of cows (in Model 1) indicates that these variables have an inverse impact on the dependent variable which conflicts with the logic of Cobb-Douglas production functions. However, the result of a negative capital coefficient is not completely rare in the applied research (Felipe and Adams, 2005; Felipe and Fisher, 2003; Latruffe et al., 2004; Lucas, 1970; Manevska-Tasevska, 2013); some even see it as standard findings. It has been argued that it could be an aggregation problem that occurs when combining production functions, and that faulty function specification may be the underlying problem in such cases (Felipe & Fisher, 2003). Felipe and Adams (2005) claim that the Cobb-Douglas function is expected to generate a positive coefficient when inputs are represented as quantities and that the regression works better without a time trend. However, when a value with information of the price is included (as the total costs variable for this study), the results may turn out to be negative. This opens up to the discussion if a new model needs to be developed to justify a negative (or zero) elasticity for capital? However, that is beyond the scope of this study.

The three models' R-squared values are considered quite low, but the issue has been highlighted by Carpentier and Letort (2012) and Bareille and Letort (2018) argue that it reflects heterogeneity among farmers production conditions. The low R-squared value may be increased with a larger size of the data sample and or more input variables in the production function. Almost all estimated parameters in Model 1 and Model 2 are significantly different from zero at the 0.05 level. The size of the selected data sample can be considered too small, and when comparing the features of the selected sample to the average Swedish dairy farm, it showed that there were significant differences even though the variables were normally distributed. The difference in average milk yield produced may be because it varies how measurements have been made. Either the milk delivered to the processor is measured, or the milk is measured at the farm and includes milk that will be sorted out. The farms in the sample were also larger in the form of more cows per farm, higher productivity, and higher BTSCC compared to the average farm in the population. Lastly, the proportion of Holstein cows in the herd per farm were lower compared to the Swedish average farm. The differences between the features of the sample compared to the entire population may affect the representativeness of the sample and thus affect the generalizability. However, all dairy producers have unique characteristics, and the selection reflects the population to some extent. The sample contained the dairy producers that voluntarily gave consent to Växa Sverige for their participation. As the new GDPR came into force during this study, the possibility of further data collection was limited, and the analyzes have been carried out based on the given conditions.

Using farm accounting data imposes some limitations. For example, the data regarding labor is not as detailed as it could have been. Labor was, therefore, a difficult factor to consider, partly because quantifying the hourly price depends on several aspects, such as who is working, the owner or employees, and their education. Secondly, the owners record the entries differently. Some of the owners book their working hours under the category labor costs, while others do not report their work under this category but only the hours worked by external workers (hired labor). Furthermore, the indirect costs, as mentioned earlier, were excluded from the analysis since they did not include the opportunity costs for example leasehold. Excluding the category means that the total costs may lack certain aspects, but if the category were included, it might have biased the results. The available data made no distinction between organic and conventional dairy, which may also have affected the results. Both the level of production inputs and output difference between the production systems along with the conditions for organic dairy farmers which faces longer withdrawal of milk from cows treated with antibiotics compared to conventional producers (Hagnestam-Nielsen and Østergaard, 2009; Nielsen et al., 2010). Organic dairy farmers also receive a higher settlement price for milk delivered, which raises the question if organic dairy producers invest more in improved animal health compared to conventional ones?

There are also other variables that are known to affect the milk output and have been used in production functions in the past. For example, McInerney (1992) and Yalcin et al. (1999) used the type of milking system and the size of the farm (hectare) when estimating production functions. Furthermore, machinery, buildings and more detailed costs of veterinary treatment have been used for analysis (e.g., Ahmad & Bravo-Ureta, 1995; Alvarez & Arias, 2004; Chi et al., 2002; Saha & Jain, 2004). Yalcin (2000) also included preventive measures in the regression analysis when estimating the production effect of mastitis. Since this study is based on existing data, information, as described above, was unfortunately not available. However, adding more variables into a regression analysis can also result in it becoming harder to interpret what value affects what in the model. The model developed in this study is meant to be used in practice by farmers, veterinarians, and other advisors, or form the basis for future research and was therefore designed simpler with fewer input variables.

A low value of invSCC does not necessarily mean that farmers have not made any investments in animal health, but it indicates that elevated/high BTSCC occur on the farm and this will affect output and milk revenue. This study, however, does not consider how investments in animal health have been made but it is assumed that farmers make decisions to benefit from the investment in animal health by reducing the BTSCC and mastitis. This is done similarly to Bareille and Letort (2018) which argued that crop biodiversity could be modelled as production factors. A farmer who knows that mastitis causes production inefficiencies, additional costs, and suffering to the cow, can be motivated to act in the prevention of mastitis, even if the BTSCC is not close to a possible penalty level. Healthy cows have economic value but not necessarily a market price. Better milk quality and higher milk yield, however, does. By generating higher income from sold milk, bonuses from lower BTSCC, less additional costs for the producer, fewer labor hours spent on treating sick cows, fewer cullings, more calves, along with other benefits of healthy cows.

$$Y = 10.162 TC^{0.082} n^{0.023} 1/SCC^{0.1} partSH^{0.112} \quad (4)$$

The findings from this study can be applied empirically on dairy producers production to illustrate how investments in improved animal health increase the milk yield. In the equation presented above (4), the results from Model 2 is presented in its Cobb-Douglas form. By using the partial output elasticity for 1/SCC (0.1), a 10% improvement in animal health (i.e., lowering the BTSCC with 10%) generate 1% more kilos ECM in output. The average farm in the data sample (see Table 1) produces 10 441.8 kilos ECM/year and has a mean BTSCC 241 028/ml. If the producer, in this case, invests in improving animal health by lowering the BTSCC with 10% (24 102.8), it will generate 104.418 kilos ECM more. By a marginal analysis, the additional benefit from investments in animal health is illustrated, indicating that there is a significant economic value of investing. However, the economic impact of the investments on the individual producers depends on which payment system the dairy processor has. The estimates from this study can be used in practice by advisors or veterinarians for the purpose of motivating preventive work against poor udder health and mastitis.

The model developed in this study can be generalized to other countries with similar production systems, especially within the European Union where the maximum BTSCC is set at 400 000 (Council Directive 92/46/EEC). The model can also be generalized to other livestock-production systems such as cattle production, pork or others. However, in such instances, the animal health variable needs to be adjusted for diseases of these production animals instead of mastitis. This model also allows for replication which strengthens the validity of the results. Replications studies are unusual in economic research, but there is a growing interest in enhancing research transparency and reproducibility (Christensen & Miguel, 2018; Hamermesh, 2007). Neither of the models suffers from heteroscedasticity, multicollinearity or omitted variables which strengthens the results.

In future research, the cost categories mentioned above can be advantageously used to see if the result is different or if the R-squared value gets higher. Also, dividing the farmers into conventional/organic or other management groups may result in different results since the conditions differ between the production systems. A further natural step for future research would also be to do a cost-benefit analysis on dairy farms investments in animal health, where the cost of improving animal health by investments in lowering the BTSCC is compared to the benefit from it.

Conclusions

The results indicate that investments in animal health play a significant role in the production process of dairy farming. The findings suggest that, for dairy farms, improving udder health (keeping everything else alike), can play a significant role in achieving an efficient and economically rewarding milk production. The actual economic impact of animal health on the individual dairy producer, however, depends on which payment system the processor has, which differ between countries and regions.

The model developed in this study can be a useful tool for evidence-based counseling in order to help dairy farms become more efficient with the management of mastitis, by lowering the BTSCC and improving animal health and the profitability of the farm. The study illustrates how the production function will statistically change when animal health is improved. The model also provides a basis for future research on the economic effect of animal health.

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