Voluntary approaches for livestock disease control, antibiotic reduction and public health – Evidence the Swiss dairy sector

Van Aken, Armin Uwe

This publication URL: https://archive-ouverte.unige.ch/unige:177287
Publication DOI: 10.13097/archive-ouverte/unige:177287

Voluntary approaches for livestock disease control, antibiotic reduction and public health – Evidence the Swiss dairy sector

THÈSE

présentée à la Faculté des sciences de la société
de l'Université de Genève
par

Armin van Aken

sous la direction de

Prof. Salvatore di Falco

pour l'obtention du grade de

Docteur ès sciences de la société
mention political economy

Membres du jury de thèse:

Prof. Juan FLORES ZENDEJAS, prèsident du jury, Université de Genève
Prof. Luisa GAGLIARDI, co-directrice de thèse, Università Bocconi, Italie
Prof. Salvatore DI FALCO, co-directeur de thèse, Université de Genève
Prof. Jochen KANTELHARDT, BOKU, Vienna, Autriche
Dr. Stefan MANN, Agroscope, Suisse

Thèse no 260

Genève, 22 Mars 2024

La Faculté des sciences de la société, sur préavis du jury, a autorisé l'impression de la présente thèse, sans entendre, par-là, émettre aucune opinion sur les propositions qui s'y trouvent énoncées et qui n'engagent que la responsabilité de leur auteur.

Genève, le 18 juillet 2022

Le doyen
Pascal SCIARINI

Impression d'après le manuscrit de l'auteur

Table of Contents

Abstract

Voluntary incentive-based approaches have played an important role in agricultural and environmental policy for decades. One field in which these approaches have had little impact so far is veterinary policy. Over time, however, a major problem in livestock farming has emerged: antibiotic resistance. This bears the potential to threaten public health, as there is a risk that these resistances could also spread to humans. Therefore, the state is obliged to take action and evaluate strategies for containment and future prevention.

This thesis examines if voluntary approaches could be used for this purpose, exemplified by the Swiss dairy sector. The aim is to provide policy makers with concrete suggestions for possible designs of such programs and provide critical information which lay the foundation for effective decision-making.

In Article 1, the status quo with regard to the frequency of antibiotic use is initially assessed. Article 2 analyzes if participation in an already existing animal welfare program affects the use of antibiotics. Finally, Article 3 examines the extent and under which circumstances farmers would participate in a subsidized veterinary herd health management program.

In more detail, Article 1 describes how many Swiss cows come into contact with antibiotics over a period of one year. In addition, it is analyzed whether there are factors that affect the amount of antibiotics used. Therefore, a total of 480 Swiss farmers were surveyed. It is found that 75 % of the farmers used antibiotics preventively, and in addition, 65% among them for therapeutic use. Hereby, the proportion of treated cows is influenced by various factors such as traditional vs

organic agriculture, the participant's personal opinion on the importance of antibiotics in farming or the role allocation in the decision-making process (veterinarian vs farmer).

Article 2 shows the effect of participating in an animal welfare program on animal health and the number of treatments with antibiotics. In the program called "Particularly animal friendly stabling", farmers get paid if they keep their cows in a free-stall barn. The required data stems from a survey conducted with 408 farmers across Switzerland. It is an observational study applying an approach called Matching Frontier. Here, the underlying principle is to create two groups that are comparable in their characteristics through matching and pruning of observations. Using this, it is found that the participants in this program achieve better animal health and fewer treatments with antibiotics.

Article 3 examines the willingness of farmers to participate in a hypothetical subsidized veterinary herd health program. In this program, a veterinarian would be specifically involved as an expert in preventive care on farms. To this end, 485 farmers were surveyed using a contingent valuation approach. It is found that 53 % of farmers would deny participating in the program. Among farms that would be willing to participate in principle, the willingness to participate increases with higher subsidy levels: If the government pays 20% of the costs and farmers pay CHF 96 per cow per year, 23.6% of farms would participate. Yet, in case the subsidy increases to 80% (CHF 24 for farmers), the participation among farmers would climb to 40.4%.

Résumé

Depuis des décennies, les approches volontaires fondées sur des incitations jouent un rôle important dans la politique agricole et environnementale. Un domaine dans lequel ces approches ont eu peu d'impact jusqu'à présent est la politique vétérinaire. Or, au fil du temps, un problème majeur est apparu dans l'élevage : la résistance aux antibiotiques. Cette résistance peut menacer la santé publique, car elle risque de se propager à l'homme. Le gouvernement est donc obligé de prendre des mesures et d'évaluer les stratégies de confinement et de prévention future.

Cette thèse examine si des approches volontaires peuvent être utilisées à cette fin, à l'exemple du secteur laitier suisse. L'objectif est de fournir aux décideurs politiques des suggestions concrètes pour la conception éventuelle de tels programmes et de fournir des informations critiques qui jettent les bases d'une prise de décision efficace.

L'article 1 évalue dans un premier temps le statu quo en ce qui concerne la fréquence d'utilisation des antibiotiques. L'article 2 analyse si la participation à un programme de bien-être animal déjà existant a une incidence sur l'utilisation des antibiotiques. Enfin, l'article 3 examine dans quelle mesure et dans quelles circonstances les agriculteurs participeraient à un programme vétérinaire subventionné de gestion de la santé du troupeau.

L'article 1 décrit plus en détail le nombre de vaches suisses en contact avec des antibiotiques sur une période d'un an. En outre, il analyse s'il existe des facteurs qui influencent la quantité d'antibiotiques utilisée. Au total, 480 agriculteurs

suisses ont été interrogés. Il s'avère que 75 % des agriculteurs utilisent des antibiotiques à titre préventif et que 65 % d'entre eux les utilisent à des fins thérapeutiques. La proportion de vaches traitées est influencée par divers facteurs tels que l'agriculture traditionnelle ou biologique, l'opinion personnelle du participant sur l'importance des antibiotiques dans l'agriculture ou la répartition des rôles dans le processus de prise de décision (vétérinaire ou agriculteur).

L'article 2 montre l'effet de la participation à un programme de bien-être animal sur la santé des animaux et le nombre de traitements aux antibiotiques. Dans le cadre de ce programme, les agriculteurs sont rémunérés s'ils gardent leurs vaches dans une étable à stabulation libre. Les données requises proviennent d'une enquête menée auprès de 408 agriculteurs en Suisse. Il s'agit d'une étude d'observation appliquant une approche appelée "Matching Frontier". Le principe sous-jacent consiste à créer deux groupes dont les caractéristiques sont comparables grâce à l'appariement et à l'élagage des observations. Cette approche a permis de constater que les participants à ce programme obtiennent une meilleure santé animale et moins de traitements aux antibiotiques.

L'article 3 examine la volonté des agriculteurs de participer à un hypothétique programme de santé vétérinaire subventionné pour les troupeaux. Dans ce programme, un vétérinaire serait spécifiquement impliqué en tant qu'expert en soins préventifs dans les exploitations agricoles. À cette fin, 485 agriculteurs ont été interrogés à l'aide d'une méthode d'évaluation contingente. Il s'avère que 53 % des agriculteurs refuseraient de participer au programme. Parmi les exploitations qui seraient en principe disposées à participer, la volonté de participer augmente avec les niveaux de subvention : Si le gouvernement prend en charge 20 % des coûts et que les agriculteurs paient 96 CHF par vache et par an, 23,6 % des exploitations participeraient au programme. Toutefois, si la subvention passe à 80 % (24 CHF pour les agriculteurs), la participation des agriculteurs atteindrait 40,4 %.

Acknowledgements

I would like to thank the members of the thesis jury consisting of Prof. Juan Flores Zendejas, Prof. Salvatore di Falco, Prof. Luisa Gagliardi, Prof. Jochen Kantelhardt and Dr. Stefan Mann for their time and effort invested, which is highly appreciated.

A special thanks goes to Salvatore di Falco. He gave me excellent support from start to finish. Without his commitment, his dedication and his patience, it would not have been possible to complete this thesis. Furthermore, he enabled me to enroll in his classes. This gave my motivation for science and my understanding of it an additional boost. In addition, he supported me to tackle the organizational and bureaucratic challenges throughout the process.

I would also like to say a big thank you to Luisa Gagliardi. Her willingness to supervise me made it possible to start this PhD. Especially in the beginning, she supported me to find access to this work.

Also, I would like to specifically acknowledge Stefan Mann for granting me the privilige to take on the National Research Program 72 (NRP 72) project "Potential of incentive-based instruments for an animal-friendly reduction in antibiotic usage" at Agroscope, which secured the funding throughout my PhD. He also continuously supported me during my time at Agroscope. As co-author of two papers, he made an immense contribution to the articles. His door was always open to my concerns and he always supported me in making progress with the project. This was the only way to produce the respective articles, which are the foundation of this work. In this regard, I would also like to thank the National Research Program.

In addition to Stefan Mann, I would like to thank my colleagues Katharina Friedli and Daniel Hoop, who contributed valuable thoughts and critical feedback which greatly improved the second article. More specifically, Katharina Friedli contributed to advance the paper conceptually. Daniel Hoop supported me greatly in analyzing the data and preparing the results.

A big thank you goes out to all of my colleagues at Agroscope. The time we have spent together has made all these years fun, yet were always a great support in more challenging times. This really helped me to move forward and stay motivated in this academic journey.

I would like to thank my family from the bottom of my heart. Without them, this work would not have been possible. My parents supported me unconditionally throughout my life. Especially over the last few years, during the time in which this work had been written, they often had my back. This also applies to my parents-in-law, whom I would also like to thank for their great interest in my work. I would like to express my deepest gratitude to my two beautiful and amazing children who have always been a source of inspiration to me – and a constant reminder of the fundamental things in life. A very special thanks goes to my wife Theresa! She has supported me to an extremely high degree over all these years. On countless occasions, she had looked after our children on her own enabling me devoting the necessary time to this work. She always had my back in challenging situations and motivated me. Without her, the work would not have become what it is today.

Tables und Figures

Chapter 1. Introduction

Livestock disease leads to a series of negative mid- and long-term effects. As an immediate effect, it causes pain and suffering for the affected animals. For livestock keepers, it leads to economic losses due to reduced productivity and high costs for treatment and medication. Moreover, it poses an imminent threat to public health when the disease is transmitted from animals to humans. The danger of these zoonoses was clearly demonstrated in the case of Covid-19. The pandemic caused many fatalities and enormous private and social costs (Padhan and Prabheesh, 2021). Another problem that is directly linked to livestock disease is antibiotic resistance. Antibiotics are a great weapon in the fight against disease. However, their excessive and widespread use can result in them no longer being effective against diseases that were originally easily treatable. As a result, antibiotic resistance has become one of the greatest challenges and threats to global health in the 21st century (WHO, 2020).

All this shows the importance of animal health management, livestock disease control and measures for responsible use of antibiotics. Livestock keepers have already taken many measures to prevent the animals from falling ill (Svensson et al., 2018). However, due to the fact that public health is under threat, the state also appears to have a duty to take action. In this regard, the state has a number of voluntary and command-and-control approaches at its disposal. Voluntary approaches are more flexible in terms of legislation and can also be effective at lower costs, provided that farmers are willing to participate (Segerson, 2013). While voluntary programs have played a role in the environmental field for decades and have been evaluated excessively (e.g. Dessart et al., 2019; Scheper et al., 2013), this approach has been slow to reach the field of policies for antibiotic reduction and resistance. The topic has been discussed in economics textbooks (Laxminarayan, 2006). However, the level was very general and theoretical and the focus was on increased investment in drug development (Alvan et al., 2011).

The present thesis has the overarching goal to change this. It aims to make concrete proposals for possible voluntary policy measures that prevent animals from falling ill and reduce the use of antibiotics. As an exemplary case, these proposals are made for the dairy sector in Switzerland. In addition to the design of the programs, potential decision-makers are provided with concrete analyses so that they have a better basis for deciding whether they consider them to be useful.

The thesis essentially consists of three parts. In the first part, more specifically in Article 1 in Chapter 2, a descriptive overview of the situation regarding the use of antibiotics in Swiss dairy farming is given. This data was obtained by means of a survey of Swiss dairy farmers and distinguishes between prophylactic and therapeutic use. A regression analysis is used to investigate whether certain factors lead to increased use of antibiotics. In the second and third part, Article 2 in Chapter 3 and Article 3 in Chapter 4, two concrete proposals for programs are made and analyses of the programs are performed.

In principle, there are countless possible starting points and measures for designing these programs. The causes of diseases are often multifactorial and there are complex cause-and-effect relationships in the field of animal health and antibiotic reduction. The proposals for the programs are two implementations from this almost endless range of possibilities. These were chosen for two main reasons.

Firstly, the question arose as to whether antibiotic reduction should be promoted either directly by paying for reaching lower antibiotic usage levels or indirectly by promoting animal health. With the first approach, there is a risk that sick animals are not treated, which would be a threat to animal welfare. This work therefore rather focuses on indirect measures that are intended to reduce the use of antibiotics by promoting animal health. The second reason for choosing these two measures was political reality:

The first program was selected because it is a policy measure that has been implemented in Switzerland for years. The advantage was that this program and the associated measures were already known and accepted by farmers and has become established over many years. This meant that no additional administrative effort was required to set up the program and monitor compliance. The second policy measure was selected for evaluation because policy makers had already considered its implementation. Therefore, in addition to a scientific interest, there was also a political interest in answering questions about the possible design of this measure.

The already existing program, which is analyzed in Article 2, has a long tradition in Switzerland. In the 1990's, Switzerland's agricultural policy shifted from a market-based support by higher product prices towards generating direct payments for Swiss farmers (Mann, 2005). Partly, these payments were coupled to the farm's cattle and land, partly they were subject to certain requirements. While most of the programs in the latter category referred to environmental issues, there was also an ethological farm program: The “Particularly animal friendly stabling” (PAS) program. Farmers are granted 90 Francs per dairy cow and year if they keep cows in free-stall barns and if feeding areas and laying areas are separated. Studies provide evidence for the success of these programs on animal health and profitability (Odermatt et al., 2018; Regula et al., 2004). However, one question that has only been answered to limited extent so far was whether the program also leads to reduced antibiotic use. If there are positive effects, this program could be adapted so that more participants would engage. The disadvantage of analyzing an existing program in an observational study is selection bias: participants are not randomly assigned, but consciously choose to participate. To control for this, a relatively new approach called Matching Frontier was used.

Finally, Article 3 analyzes a program that was developed specifically to improve animal health and thus, reduce the use of antibiotics. The aim of this ex-ante analysis was to gain possible insights into the decision-making process of farmers in advance so that the program could be designed accordingly. While for some livestock disease settings possible interventions are straightforward, for example vaccination strategies in a certain region, other underlying problems ultimately leading to an increased sickness rate of animals are more complex.

An example are udder diseases as part of dairy production, for example mastitis. This is one of the main reasons for antibiotic usage in cows, causing high costs for farmers and the public. Problems are often multifactorial and farm-specific, and weak points, for example in biosecurity measures, are heterogenous among farms. These situations require diverse and farm-specific preventive advice and actions, which could overstrain the state with its scarce resources. Instead of setting up an expensive and inefficient apparatus of experts, one possibility would be to indirectly support farmers by bringing accredited animal health experts on board, namely veterinarians.

Farmers see their veterinarian as the first source of knowledge for dealing with udder health problems (Tschopp et al., 2015). Sok et al. (2015) showed that the government representative was one of the least important referents when it comes to the change of attitudes regarding livestock disease control, while the veterinarian and peer farmers were more important referents. As a result, government communication provided through veterinarians is more effective than provided directly (Sok et al., 2018).

Here, the government could make use of the trust that famers have in their veterinarian to counter animal health problems with possible negative effects for public health and food security. However, it does not make sense to subsidize veterinary services as a matter of principle. To select appropriate measures, Umali et al. (1992) and Rushton (2009) provide a framework. This is based on public and the new institutional economics to characterize market structure and failures in animal health management and veterinarian services in terms of private vs. public goods, externalities and transaction costs.

Public goods are those where it is difficult or impossible to exclude others from their usage, which in the animal health context refers to disease surveillance, prevention, control and eradication of highly contagious diseases with serious socio-economic, trade and public health consequences.

Pure private goods are for example clinical diagnosis and treatment of sick animals. Umali et al. (1992) concludes that where goods are public, where externalities and moral hazard are small, there is no imperative for the government to act. Public intervention should only address issues where market failures occur. These services offered by veterinarians to their clients were formalized in a program, namely veterinary herd health management (VHHM).

VHHM combines animal health, food safety, animal welfare and public health with farm management and economics. VHHM comprises a basic structure of goal setting, planning, execution and evaluation. Farms are visited every two to six weeks, independent of the animals' health status, where the veterinarian inspects the animals, evaluates gathered data and provides advice on livestock disease control and preventive measures, such as implementation of higher biosecurity standards.

A range of studies have already dealt with VHHM to find out more about farmers perception and attitudes towards VHHM. Using qualitative approaches and surveys, they wanted to identify reasons for low participation rates. In most cases, farmers mentioned high costs for VHHM as number one reason for avoidance of participation (Derks et al., 2012; Gerber et al., 2020; Hool et al., 2020; Svensson et al., 2018), followed by low or unclear cost-benefit ratio (Svensson et al., 2018). These results show that economic aspects play a major role and give rise to the assumption that public intervention, for example subsidies for the services offered, could have a positive effect on dissemination rates.

However, these studies do not provide deeper economic insights and remain too superficial to derive aspects for the design of such a public support. It would be helpful, for example, to have more information on farmers' mean willingness-to-pay (WTP) or the distribution of the WTP in order to be able to determine the necessary level of subsidies for a targeted number of participation rates. WTP studies have proven their worth in the area of agricultural policy in terms of an ex-ante evaluation of planned programs. This partly also applies to animal health management and livestock disease control, where stated preference approaches including contingent valuation (CV), which is also applied in this Article, and choice experiments (CE) helped to inform policy makers (e.g. Bennett and Balcombe, 2012; Sok et al., 2018).

Chapter 2. Article 1: Pushing or Pulling? An Institutional analysis of antibiotic usage in Dairy Farming

Armin van Aken [a b], Stefan Mann [b]

[a] University of Geneva, Geneva School of Social Sciences, Boulevard du Pont d' Arve 40, 1211 Geneva, Switzerland

[b] Agroscope, Research Division Competiveness and System Evaluation, Tänikon 1, CH-8356 Ettenhausen, Switzerland

Published in:

Visionen für eine Agrar- und Ernährungspolitik nach 2020. Vol. 54, Ed. Gewisola, Landwirtschaftsverlag. 2019, 165-176.

https://www.openagrar.de/receive/openagrar_mods_00050982

Abstract

Emerging resistance is a negative externality of the generous use of antibiotics in animal farming. The reduction of usage is an effective strategy to tackle resistance. To develop such a strategy, it is important to know what factors drive the quantity of antibiotic used. In a written survey of Swiss dairy farmers, the amount of antibiotics used and several external, internal and personal farm- and farmer-related factors were recorded. The inclusion of two parties in the decision-making process makes a significant difference to environmental conservation measures: the farmer always needs a vet for prescribing drugs. This leads to a complex interplay that results in antibiotic usage only if both sides support the decision. Therefore, this study additionally asked farmers about the role allocation of vets and farmers in the decision-making process about antibiotic usage in general and in drying off cows. The results show that the role allocation is different depending on the setting. For drying off, inclusion of the vet in the decision-making led to less antibiotic usage, but in the treatment of sick animals, more antibiotics were administered if the vet was included. Other factors leading to less antibiotic usage were organic farming, complementary methods like homeopathy and the belief that animal production without antibiotics is possible. This implies that both the farmer and the vet are crucial to measures for internalising negative externalities.

Keywords

Dairy farming, antibiotics, veterinarians

2.1 Introduction

Antibiotics are a key tool in human and animal health. Their introduction has reduced mortality rates and opened new options for combatting diseases. Nevertheless, their generous use creates many negative externalities. One of these is the emergence of resistance. Antibiotic resistance is a growing topic of discussion (Ministerium für Umwelt- und Naturschutz, 2004; Johnson et al., 2016), and has even been described as a 'perfect storm' (Shlaes, 2010) due to the narrowing options for effective medical treatment.

Over recent decades, the externalities of agricultural production in other realms have received ample attention. Agri-environmental issues, in particular, can be considered as well understood in terms of farmers' decision making, as there is a vast amount of research (for meta analyses see Knowler and Bradshaw, 2007 or Lastra-Bravo et al., 2015). This knowledge has enabled efficient policies for internalising environmental effects through governmental programs. This kind of knowledge is largely missing in regard to the use of antibiotics. Theoretical considerations have been developed with some rigour (Dijkhuizen and Morris, 1996; Chilonda and van Huylenbroeck, 2001), but the few empirical studies usually suffer from low sample sizes (Vaarst et al., 2002; Vaarst et al., 2003; Alarcon et al., 2014; Visschers et al., 2014) and therefore offer only limited insights into the influencing factors.

Decisions to either use or conserve antibiotics differ from other on-farm decisions in a way that certainly deserves a more thorough discussion. While farm managers make their own decisions about pesticides, fertiliser and tillage or harvesting times, in most developed countries it needs a vet to prescribe antibiotics. This leads to a complex interplay which will be, among other factors, explored in Section 2. The survey and model designed to identify the decisive factors affecting antibiotic usage are presented in Section 3, results are shown in Section 4 and conclusions drawn in Section 5.

2.2 Factors related to antibiotic usage

Various factors play a role in the process of deciding if antibiotics are to be administered or not. These can be divided into external/physical farm factors (e.g. the number of animals and their housing conditions), personal variables (e.g. the farmer´s age) and internal variables (e.g. the individual characteristics of farmers, such as their attitudes towards antibiotics, their beliefs about antibiotic resistance, their perceived control over the need for antibiotics and their farming goals) (Visschers et al., 2014, Willock et al., 1999).

In addition to these farm- and farmer-related factors, one major aspect should not be neglected. This is the role of the vet. As noted above, in most developed countries it takes a veterinarian to prescribe antibiotics, and this is the case in Switzerland. Strict regulations, enforceable by law, confine the use of antibiotics to specific situations.

While the attitudes of farmers and veterinarians have occasionally been compared (Gunn et al., 2008; Hall and Wapenaar, 2012; Thomsen et al., 2012), their interplay in the use of antibiotics (or other prescription drugs) has, to our knowledge, never been explored. Table 1 makes an initial attempt at this, indicating that pharmaceuticals will be used only if both farmers and veterinarians support this decision. Thresholds are therefore higher than for other production factors.

Ch.2 Table 1. A simple model of interplay in the usage of animal medicine

	Farmer against	Farmer for
Vet against	*No usage*	*Demand without prescription*
Vet for	*Prescription without usage*	*Usage*

Source: own presentation

Although both the farmer and the vet need to come to a common decision in the decision-making process, the role allocations of the farmer and the vet are not necessarily distributed equally. It may be that one party has a stronger influence depending on the personality, knowledge and experience of the persons involved. Another factor that can play a role is the situation in which the usage of antibiotics is discussed. Two situations for the administration of antibiotics can be distinguished. The first is the case of a sick animal that has to be cured, and the second is the drying off of cows where antibiotic drying agents can be applied prophylactically to prevent mastitis. These two settings can cause different role allocations between the vet and the farmer. A farmer may have different motives for calling a vet to treat a sick animal. On the one hand, it could be that, drawing on previous experience and knowledge, the farmer knows that the situation requires the administration of antibiotics and only needs the vet to prescribe them.

On the other hand, there is the possibility that the farmer does not know how to cure the sick animal and thus depends on the help and advice of a vet. In this case, a decision about using antibiotics lies more in the hands of the vet. A third possibility could be that the farmer calls the vet to discuss in person if antibiotics should be used.

The other setting involves the use of antibiotic drying agents. Every cow has to be dried off once a year, so this is a very common situation in dairy farming. Drying off cows before they give birth to calves is an important step in the production cycle. At this point, an antibiotic with a long-term effect can be administered to the udder. This practice is still very popular as it supports the regeneration process of udder inflammations and can prevent new incidences of mastitis. The prophylactic use of antibiotics presents a very interesting situation, as it includes two issues. The first issue is whether or not antibiotics are administered, and the second is who makes this decision, the manager of the farm, the vet or both together. The question is whether different decision-making processes lead to a higher or lower use of antibiotics. Farmers have a lot of experience with this situation, and this could lead to a higher rate of farmers making their own decisions about the use of drying agents. However, there is also the possibility of including the vet in making their decision.

Taking the possible combinations of settings and role allocations together, different questions emerge:

- Which factors (external, personal, internal) determine the amount of antibiotics used on a farm?

- Is it significant if it is primarily the farmer, the vet or both together who decide if antibiotics are or are not administered?
- Do the relevant factors vary from the setting of a sick animals to the setting of prophylactically applied antibiotic drying agents?

2.3 Method

2.3.1 Study Design

We conducted an online and mail survey in Switzerland between August and November of 2017. A random sample of 2,000 animal farmers all over Switzerland was asked to complete the questionnaire. Contact data for the farmers was provided by the Federal Office of Agriculture. The sample was selected from a data base registering all farmers receiving direct payments (AGIS).

The selected farmers were sent a letter inviting them to take part in the online survey. Three weeks later, a reminder was sent to those who had not yet completed the online questionnaire. This reminder contained the paper-and-pencil questionnaire and a stamped, addressed return envelope. The online questionnaire was completed by 249 farmers and 599 returned the paper-and-pencil questionnaire. The final sample included 848 famers, giving a response rate of 42 per cent. The research question and results presented in this paper are part of a broader project examining the incentive-based reduction of antibiotics in the three main categories in Switzerland of cattle, pig and poultry farming. The following analysis will focus on the results for dairy farmers, as this category plays the most important role in Switzerland and was best represented in our final sample. 480 (56.6%) were dairy farmers and thus formed the base of our analysis.

2.3.2 Questionnaire

The questionnaire comprised a four-page general part to be filled in by all farmers irrespective of the animal category they had on their farms. Additionally, a four-page questionnaire was developed for each single animal species. In total, this led to an eight-page questionnaire for dairy farmers.

The questionnaire was developed with the help of leading Swiss experts on animal health and production. A central aim of the questionnaire was to find out more about the amount of antibiotics used by each farmer. The majority of the participating farmers did not keep a treatment journal recording every administration of antibiotics, and we had to find a way to approximate the amount. This was done by asking about the proportion of animals treated with antibiotics in the last 12 months. As we were interested in the difference between the prophylactic and the therapeutic use of antibiotics, we asked separately about these. To explain the differences in the amount of antibiotics used, several topics were included.

The issue of the relations between the farmer and the vet was tackled by different parts of the questionnaire. First, the farmer was asked to evaluate the role allocations of the farm manager and the vet regarding the administration of antibiotics in general. The farmer could decide between five options. Option one described a situation where the farmer decided without considering the opinion of the vet. Option five was the opposite of this, where all decision-making was left to the vet. Option three described a role allocation where the decision-making included both the farmer and the vet equally. Options two and four both included the farmer and the vet, but with greater weight given to one of the parties. In addition to this general evaluation of the allocation of roles, farmers were asked to evaluate the situation during drying off.

As mentioned above, to control for external, personal and internal variables with a possible influence on the antibiotic usage, other topics including farm structure, the characteristics of the animal production system and the attitudinal and demographic characteristics of the farmer were included. A more detailed description of these variables can be found in Section 3.3.

The original questionnaire was developed in German. Comprehension of the content and wording of the questions was pretested with a small convenience sample of Swiss animal farmers. It was then translated to French and Italian for the non-German speaking Swiss population.

2.3.3 Model

The goal of the analysis was to identify and quantify the variables that determine the proportion of animals treated with antibiotics. Therefore, an estimate of the influence of the relevant variables of this proportion was made.

We estimated two different models, one involving the prophylactic use of antibiotic drying agents and one for the therapeutic treatment of sick animals. Their structure was identical; the difference lay in the dependent variable and in the question about role allocation. In the first case, this asked about the use of drying agents, and in the second case it asked about antibiotics in general and for sick animals.

The dependent variable y is the proportion of animals treated and lies between the 0 and 1 ($0 \leq y \leq 1$). If the dependent variable is limited, as for example in the case of a fraction, the predicted values of y conditional on x will not necessarily lie within the boundaries of 0 and 1 using an Ordinary Least Square (OLS) (Götze et al., 2016). Therefore, an OLS is not suitable.

We relied on the approach developed by Papke and Wooldridge (1996). This approach is suitable for limited dependent variables that lie within certain boundaries. It is also useful for skewed distributions and data with high numbers of zeros. They proposed a generalised linear model (GLM). The assumption of the model is that all observations i:

$$(1)\ E(y_i|\mathbf{x_i}) = G(\boldsymbol{x_i}\beta)$$

where y_i is statistically independent with no grouping or clustering of the data. G(.) is a known and correctly specified transformation function (Götze et al., 2016). This function ensures that the expected value of y lies between zero and one. A suitable transformation function for our case is the logit link function, as it is suitable for fractions (Papke and Wooldridge ,1996).

The final empirical model looks as follows:

$$(2)\ E(scows_i|x_i) = G(\beta_0 + \beta_1 organic_i + \beta_2 land_i + \beta_3 nrcow_i + \beta_4 work_i + \beta_5 welfare_i + \beta_6 outdoor_i + \beta_7 homeo_i + \beta_8 vet_i + \beta_9 both_i + \beta_{10} age_i + \beta_{11} gender_i + \beta_{12} resis_i + \beta_{13} import_i + u_i)$$

The dependent variable, the proportion of cows treated with antibiotics ($scows_i$), is the fraction of treated animals on farm i. In the first model, it is the proportion of cows treated with antibiotic drying agents; in the second, it is the proportion of animals treated due to sickness. The following variables were included to cover external, internal and personal variables and the role allocation between the vet and the farmer. To capture the production system, a dummy variable for organic production ($organic_i$) was included. The total amount of land that was cultivated

($land_i$) and the number of animals ($nrcow_i$), in this case cows, determined the basic structure of the production of the farm. In Switzerland, two incentive-based programs for animal-friendly farming exist. These were included due to their possible effects on animal health and therefore on antibiotic usage. Two dummy variables for taking part in the program for high welfare status regarding stables and housing ($welfare_i$) and for regular outdoor access ($outdoor_i$) were included. Alternative treatment methods and complementary medicine can be substituted for the usage of antibiotics. This was captured by a dummy variable for the usage of homeopathy ($homeo_i$). The farmer's statement about role allocation vis-à-vis the vet is a nominal variable. Three categories were included: the decision-making lies more with the farmer, with the vet or with both. These three categories are represented by two dummy variables, one where the vet (vet_i) decided more and one where both ($both_i$) decided. The reference category of the two dummies was the farmer. Two demographic questions about the age (age_i) and sex ($gender_i$) of the farmer were added. In the case of gender, a '1' signified male and a '0' signified female. Additionally, two questions about the participant's personal opinion of the importance of antibiotics in animal production and the risk of antibiotic resistance were added. In the first, the farmer could score the risk of increased production costs, more sick animals and the danger that more animals would die in a case of a total ban on antibiotics on a five-point Likert scale from 'no risk' to 'very high risk'. The variable included in the model is the mean of these three answers ($import_i$). The second question asked about the risk that animals could become resistant to antibiotics ($resis_i$).

Descriptive and analytic statistical analyses were performed using commercially available software (Stata Version 14.1, StataCorp 2015). The two models were estimated in Stata by Maximum Likelihood.

2.4 Results and Discussion

2.4.1 Descriptive results

The sample comprised 91 per cent male and 9 per cent female farmers. The mean age of the farmers was 48.22 years (SD 9.89). Thirteen per cent of the sample produced according to the guidelines for organic farming. On average, there were 2.24 workers on a farm (SD 1.8) and 27.54 hectares were cultivated (SD 18.46). The farmers had an average of 26.22 (SD 16.76) cows, with a maximum of 120 cows owned by one farmer. Cows were kept in a loose-house stable by 43.13 per cent of the farmers, and the remaining 56.87 per cent kept their cows tethered.

The majority of the farmers (88.26 per cent) took part in the animal welfare program for open air access, and 50.94 per cent were in the high-welfare housing program. Forty-five per cent of the sample produced for a label like IP Suisse or Coop. and 43.58 per cent received help from a feed consultant. Nearly half the farmers (48.12%) used homeopathic methods, and nearly the same number (46.93 per cent) used plant-based alternative medicines.

Several questions about the attitude of the farmer were included in the questionnaire. Farmers were asked on a five-point Likert scale how they saw the risk of antibiotic resistance in animals and humans due to the use of antibiotics in animal farming. The scale went from ‘1 - No risk at all’ to ‘5 - Very high risk’. The mean score on this scale was 3.22 (SD 1.05) for resistance in animals and 2.90 (SD 1.09) for humans. In another question, farmers were asked their opinion about the risk that consumers would refuse products coming from animals that had been treated with antibiotics. The mean response was 3.21 (SD 1.08). The farmers were also asked how they assessed the risk that politicians would tighten the laws on antibiotic usage. They saw this risk as relatively high, with a mean response of 3.80 (SD 0.97).

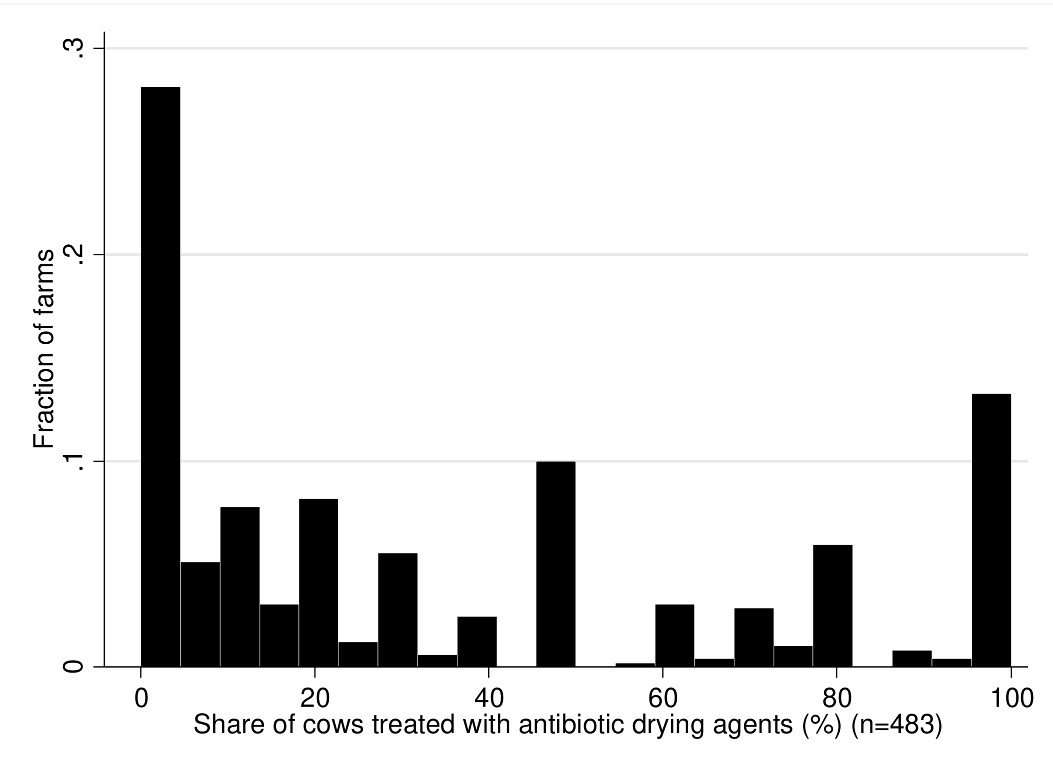
The farmers were asked about their use of antibiotic drying agents in the last 12 months. The picture differed between the different farms (see Figure 1): 25.9 per cent of the farms did not administer any antibiotics prophylactically and 13.27 per cent treated 100 per cent of their animals. Within this range, the number of animals treated was evenly distributed.

The picture differed slightly for cows treated with antibiotics due to sickness (see Figure 2). During the preceding 12 months, 35 per cent of farmers had not treated cows with antibiotics. However, many more farms had used antibiotic due to sick cows for between 1 and 30 per cent of their cows than had done this for between 30 and 100 per cent of cows. Only four farms had treated 100 per cent of their animals.

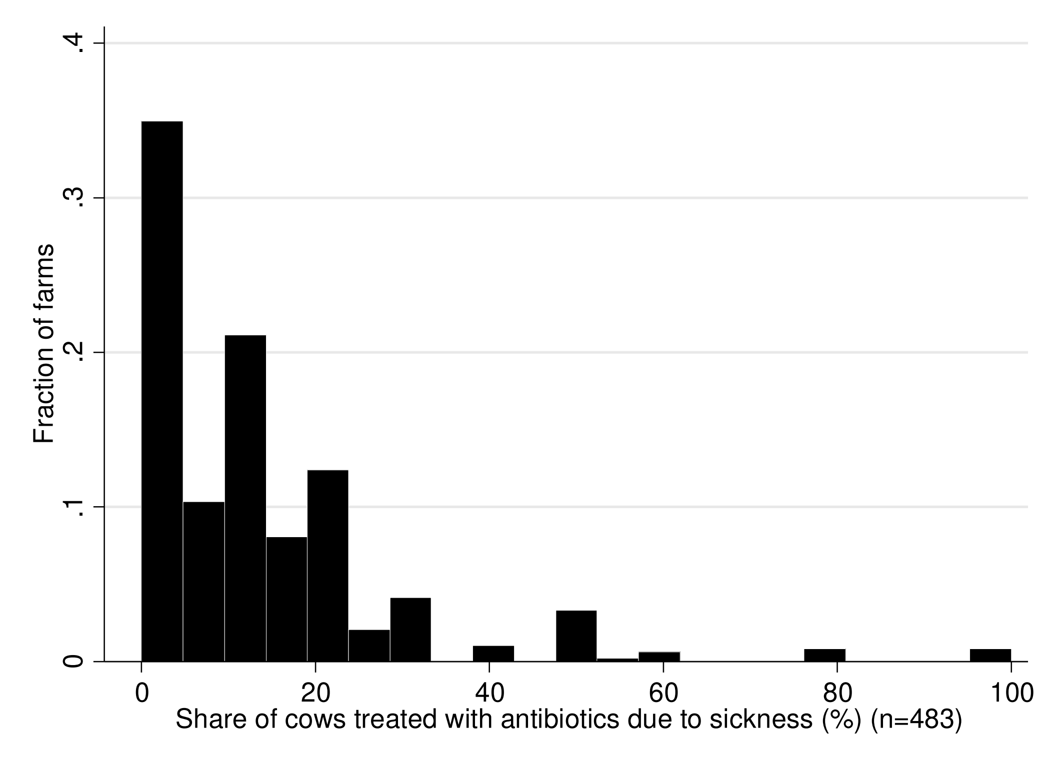
As described above, we were interested in the role allocation of farmers and vets. To evaluate this, we offered five possibilities. As only a small number of farmers stated that either they or a vet were solely responsible for decisions about treating sick cows with antibiotics, we combined the results into three categories. Figure 3 shows the results. A total of 44.30 per cent of farmers said that both parties were equally included in the decision-making; 27.42 per cent saw themselves as having the last word about antibiotics and 28.27 per cent followed the advice of the vet.

The situation was different for the administration of antibiotic drying agents. Many farmers who allowed the vet an important role regarding antibiotics in general had a different opinion about antibiotics for drying off cows (see Figure 4). The majority of farmers (64.67 per cent) made their own decisions about administering antibiotic drying agents and only 2.57 per cent allowed a vet to decide.

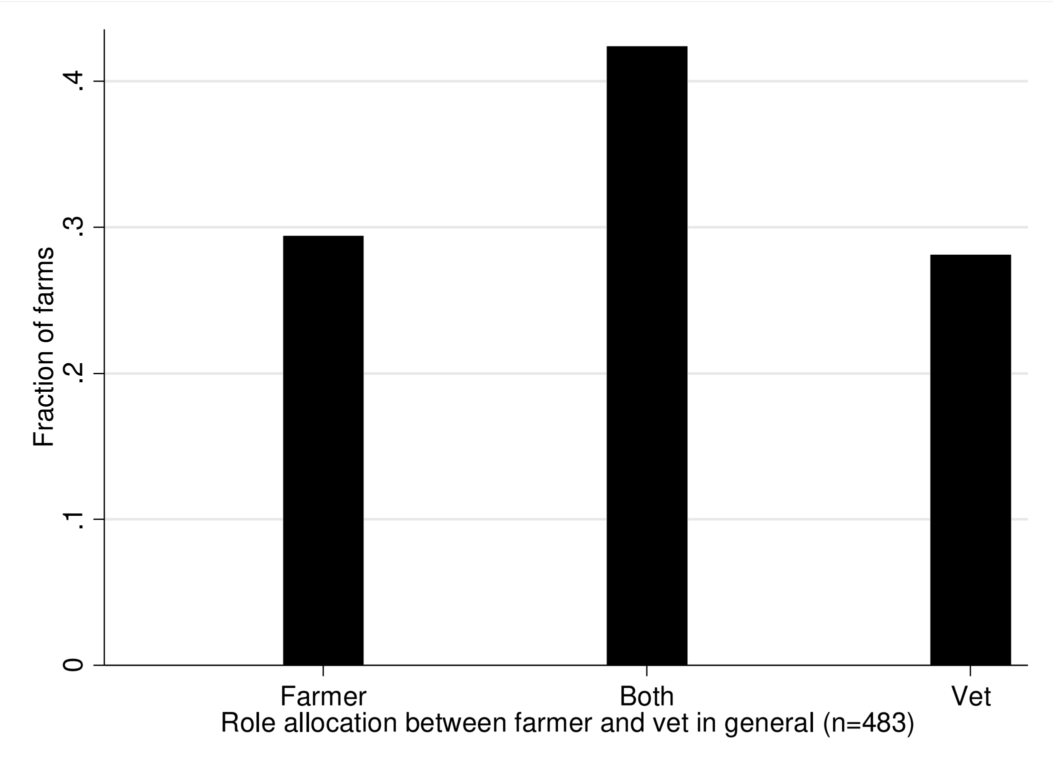
Ch.2 Figure 1. Proportion of cows treated prophylactically with antibiotic drying agents



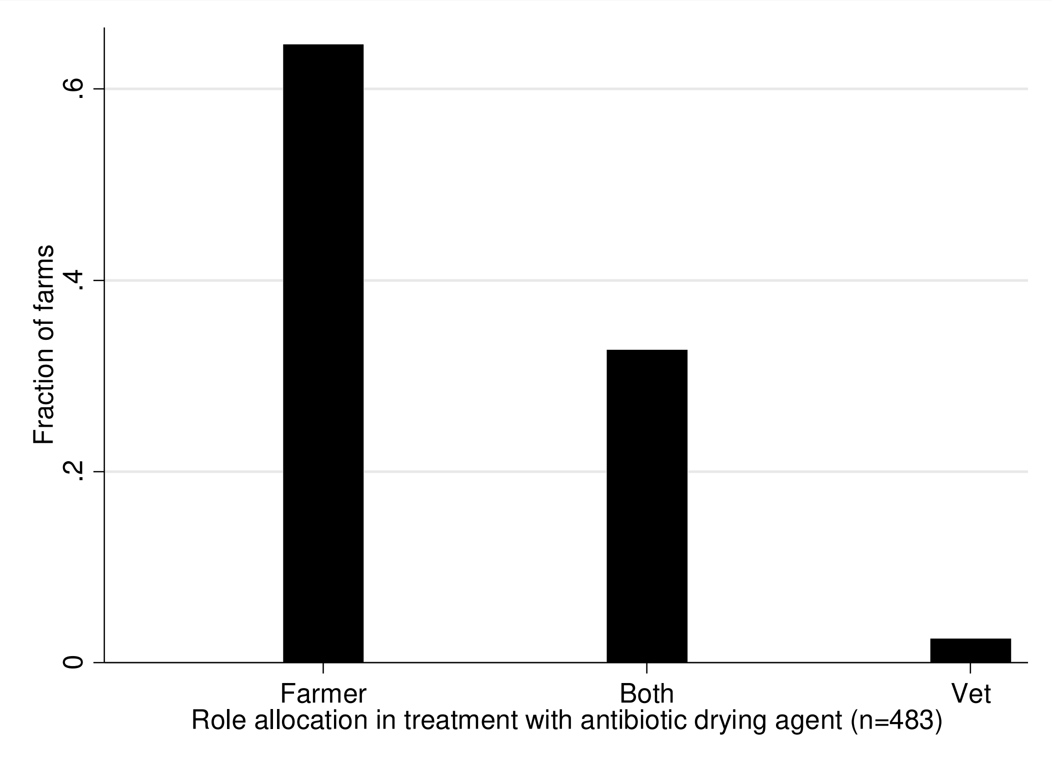
Ch.2 Figure 2. Proportion of cows treated with antibiotics due to sickness



Ch.2 Figure 3. Role allocation between vet and farmer in general and in case of sick animals



Ch.2 Figure 4. Role allocation between vet and farmer in drying off cows



2.4.2 Analytical results

Tables 2 and 3 (below) show estimates of the influence of each of the variables. These results help to answer the research questions in Chapter 2.

Table 2 shows the results for the usage of antibiotic drying agents. It can be seen that the variables for organic farming (*organic)*, participant's personal opinion of the importance of antibiotics in animal production (*import)* and the role allocation in the decision-making more on the vet´s side *(vet)* have a significant influence on the proportion of cows treated. Organic farming results in a significantly lower use of prophylactic antibiotics. This can be explained by the more restrictive laws and guidelines governing organic farming. The administration of antibiotic drying agents is only allowed if an antibiogram has been performed, raising the barriers for the use of antibiotics. Depending on the result of the antibiogram, a suitable antibiotic can be applied. An additional explanation could be a stronger focus on animal health and the lower performance of the animals.

The other significant factor is the opinion of the farmer about the importance of antibiotics for a functional and economic profitable farm system. In this case, it is very difficult to distinguish between cause and effect. It could be that due to high usage, some farmers believe that antibiotics are very important, but the inverse could be true: due to their belief about their importance, they use a lot of antibiotics. The important outcome of this question is that there is a strong correlation between the beliefs of farmers and their actual behaviour. A possible intervention strategy might be to provide information and raise the awareness that it is possible to dry off cows without using antibiotic drying agents. Suitable alternatives would have to be presented, and it has to be made clear that they work as effectively. A change in the belief system of farmers may lead to a significantly lower usage.

Another factor that influenced the number of cows treated with antibiotic drying agents applied on the farm is role allocation. This is interesting, as we were especially interested in this topic in our second research question. The results show that if a vet decides whether or not to apply drying agents, the usage is significantly lower. However, it should be noted that only 12 farmers stated that the decision was made solely by the vet. A possible explanation for those farmers' lower use of antibiotics may be that they were intentionally trying to reduce drying agents. This situation can be new and challenging to them, explaining why they rely on the expertise of a vet. Possibly the vet brings some knowledge from other farmers and helps the farmer to decide which cows need drying agents and which can be dried off without them.

The importance of role allocation was even more apparent in the treatment of sick animals, as shown by Table 3. If the decision-making depended more on the manager, there was a significantly lower usage of antibiotics. The opposite applied to the prophylactic use of antibiotics, and the explanation for this is not clear. A possible answer may be that farmers only call the vet if they do not know how to deal with the sick animal. They depend on the expert knowledge of the vet. Farmers with higher rates of sick animals need the vet more often. As these animals are often very sick, for example, with mastitis, the best medication is antibiotics. As the vet is the person recommending this this type of treatment, the farmer has the impression that the role allocation in the decision-making process gives more weight to the vet. This is more a case of correlation than cause and effect, and it cannot be concluded that the vet actively encourages the farmer to administer more antibiotics. Some vets have even reported feeling that the farmers ask them to use antibiotics (McDougall et al., 2017), and some farmers distrust more conservative methods and want the vet to administer antibiotics. However, despite the uncertainties about whether the vet is pushing or pulling, it can be said that the role of the vet is very important and that vets play a central role in effective intervention strategies.

Ch.2 Table 2. Regression on proportion of animals treated with antibiotic drying agents

Explanatory variables		Coefficient	Robust SE	Marginal Effect
External variables	$organic_i$	-0.962***	0.322	-0.183***
	$land_i$	0.005	0.004	
	$nrcow_i$	-0.002	0.005	
	$work_i$	-1.015	0.790	
	$welfare_i$	0.018	0.156	
	$outdoor_i$	0.018	0.214	
	$homeo_i$	-0.115	0.141	
Role allocation	vet_i	-1.034**	0.409	-0.189***
	$both_i$	-0.191	0.142	
Personal variables	age_i	0.003	0.007	
	$gender_i$[a]	0.198	0.352	
Internal variables	$resis_i$	-0.082	0.071	
	$import_i$	0.224***	0.081	0.051***
	$Constant\ term$	-1.426**	0.635	

Notes: No. of observations: 305; the marginal effects are depicted for those variables that are significant determinants of the proportion of animals treated with antibiotic drying agents. [a] '1' male, '0' female;

Significance levels: *p<0.1; **p<0.05; ***p<0.01

Ch.2 Table 3. Regression on proportion of animals treated with antibiotics due to sickness

Explanatory variables		Coefficient	Robust SE	Marginal Effect
External variables	$organic_i$	-0.373*	0.211	-0.034*
	$land_i$	0.003	0.004	
	$nrcow_i$	-0.005	0.005	
	$work_i$	-1.382	1.004	
	$welfare_i$	0.150	0.180	
	$outdoor_i$	0.091	0.247	
	$homeo_i$	-0.247*	0.138	
Role allocation	vet_i	0.343*	0.184	0.037*
	$both_i$	0.280*	0.166	0.028*
Personal variables	age_i	-0.002	0.008	
	$gender_i$ [a]	0.942***	0.217	0.071***
Internal variables	$resis_i$	0.092	0.070	
	$import_i$	0.350***	0.084	0.036***
	$Constant\ term$	-4.481***	0.707	

Notes: No. of observations: 455; the marginal effects are depicted for those variables that are significant determinants of the proportion of animals treated with antibiotics due to sickness. [a] '1' male, '0' female;

Significance levels: *p<0.1; **p<0.05; ***p<0.01

As seen in the prophylactic case, the importance of the farmer's belief can also be seen in the therapeutic use of antibiotics. This confirms that antibiotic reduction strategies should take into account the existing mindsets of the farmers about the importance of antibiotics. It needs to be made clear that alternatives to antibiotics exist and can sometimes be substituted for them. Homeopathy is possible example of an alternative that might lead to less antibiotic usage in the treatment of sick animals. Homeopathy is a controversial concept and method, but it is gaining more and more acceptance among dairy farmers. The decisive factor is probably not the administration of homeopathic globules, but a strong focus on observing an animal's health and reacting as soon as the first signs of a sickness are visible. There is also a strong trust in the self-healing capacities of animals, which makes the usage of antibiotics redundant. Homeopathy and alternative methods are more often used by females, which could explain why male farmers have a significantly higher usage of antibiotics.

The other external factors do not show a significant effect, which shows that farm structure is not a decisive factor in the amount of antibiotics administered. The characteristics of the farmer and the type of farming are considerably more important, and the vet also plays an important role.

The question is whether our method was accurate enough to capture the real role allocation between vets and farmers. It should be noted that only farmers were asked about this, as the study design precluded asking vets. Another drawback is that the answers were self-reported responses to a single question. A more specialised questionnaire addressing only this issue could include additional and different questions. Another possibility would be a qualitative approach with interviews or capturing real discussions during the decision-making process.

2.5 Conclusions

While over recent decades, agricultural economists have deeply explored the mechanisms of input reduction in arable farming, they have largely neglected the overuse of antibiotics in animal farming. It may be that the increased complexity of the institutional setting could have contributed to this imbalance. While farm managers make their own decisions about applying fertiliser and pesticides, decisions about using antibiotics are made in cooperation with a vet. A complex interplay between the diverging interests of the two parties will determine the decision they make together about using the drug.

Two different settings were compared. The first setting involved sick animals, and the second concerned the drying off of cows, an important part of the production process of dairy farming. This study suggests that the manager is more instrumental in making decisions about drying off than in deciding on the treatment for sick animals.

This study confirmed empirically that in dairy farming, decision-making about antibiotics is not invariably dominated by one party or the other. The influence of the vet reduces the amount of antibiotics used for drying off and increases their usage in the treatment of sick animals. Other important factors are the farmer’s belief in the importance of antibiotics, organic farming and the use of alternative methods like homeopathy.

This shows that there is no simple solution for the reduction of antibiotics. Effective intervention strategies must consider the vet and the farmer's belief in the importance of antibiotics and show that alternatives to this practice exist and are a feasible solution to curing sick animals.

References

Alarcon, P., B. Wieland, A.L.P. Mateus, C. Dewberry (2014): Pig farmers' perceptions, attitudes, influences and management of information in the decision-making process for disease control. Preventive Veterinary Medicine 116 (3) 223-242

Besser, T., S. Mann (2015): Which farm characteristics influence work satisfaction? An analysis in two agricultural systems. Agricultural Systems 141, 107-112 (2015)

Chilonda, P., G. van Huylenbroeck (2001): A conceptual framework for the economic analysis of factors influencing decision-making of small-scale farmers in animal health management. Revue scientifique et technique 20 (3) 687-700

Dijkhuizen, A.A., R.S. Morris (1996): Animal health economics. Sydney: University of Sydney

Götze, F., S. Mann, A. Ferjani, A. Kohler, T. Heckelei (2016): Explaining market shares of organic food: evidence from Swiss household data. British Food Journal 118 (4) 931 - 945

Gunn, G.J., C. Heffernan, M. Hall, A. McLeod, M. Hovi (2008): Measuring and comparing constraints to improved biosecurity amongst GB farmers, veterinarians and the auxiliary industries. Preventive Veterinary Medicine 84 (3-4) 310-323

Hall, J., W. Wapenaar (2012): Opinions and practices of veterinarians and dairy farmers towards herd health management in the UK. Veterinary Record 170, 441

Johnson, T.A., R.D. Stedtfeld, Q. Wang, J.R. Cole, S.A. Hashsham, T. Looft, Y.-G. Zhu, J.M. Tiedje (2016): Clusters of Antibiotic Resistance Genes Enriched Together Stay Together in Swine Agriculture mBio 7 (2) 14-15

Knowler, D., B. Bradshaw (2007): Farmers' adoption of conservation agriculture: A review and synthesis of recent research. Food Policy 32 (1) 25-48

Lastra-Bravo, X.B., C. Hubbard, G. Garrod, A. Tolon-Becerra (2015): What drives farmers' participation in EU agri-environmental schemes: Results from a qualitative meta-analysis. Environmental Science and Policy 54 (12) 1-9

McDougall, S., CWR. Compton, N. Botha (2017): Factors influencing antimicrobial prescribing by veterinarians and usage by dairy farmers in New Zealand. New Zealand Veterinary Journal 65(2) 84-92

Ministerium für Umwelt und Naturschutz (2004): Resistenzentwicklung und Rückstände in der landwirtschaftlichen Tierhaltung. Düsseldorf: MNU

Papke, L.E. and Wooldridge, J.M. (1996): Econometric methods for fractional response variables with an application to 401 (k) plan participation rates. Journal of Applied Econometrics 11 619-632

Shlaes, D.M. (2010): Antibiotics – the perfect storm. Heidelberg: Springer

Thomsen, P.T., I. Anneberg, M.S. Herskin (2012): Differences in attitudes of farmers and veterinarians towards pain in dairy cows. The Veterinary Journal 194 (1) 94-97

Vaarst, M., B. Paarup-Laursen, H. Houe, C. Fossing, H.J. Andersen (2002): Farmers' Choice of Medical Treatment of Mastitis in Danish Dairy Herds

Based on Qualitative Research Interviews. Journal of Dairy Science 85 (4) 992-1001

Vaarst, M., S.M. Thamsborg, T.W. Bennedsgaard, H. Houe, C. Enevoldsen, F.M. Aarestrup, A. de Snoo (2003): Organic dairy farmers' decision making in the first 2 years after conversion in relation to mastitis treatments. Livestock Science 80 (1-2) 109-120

Visschers, V.H.M., D.M. Iten, A. Riklin, S. Hartmann, X. Sidler, M. Siegrist (2014): Swiss pig farmers′ perception and usage of antibiotics during the fattening period. Livestock Science 162 (2) 223-232

Willock, J., Deary, I.J., McGregor, M.M., Sutherland, A., Edwards-Jones, G., Morgan, O., Dent, B., Grieve, R., Gibson, G., Austin, E. (1999): Farmers' attitudes, objectives, behaviors, and personality traits: The Edinburgh study of decision making on farms. Journal of Vocational Behavior.54, 5–36

Chapter 3. Article 2: Udder health, veterinary costs, and antibiotic usage in free stall compared with tie stall dairy housing systems: An optimized matching approach in Switzerland

Armin van Aken [a b], Daniel Hoop [b], Katharina Friedli [c], Stefan Mann [b]

[a] University of Geneva, Geneva School of Social Sciences, Boulevard du Pont d′ Arve 40, 1211 Geneva, Switzerland

[b] Agroscope, Research Division Competiveness and System Evaluation, Tänikon 1, CH-8356 Ettenhausen, Switzerland

[c] Federal Food Safety and Veterinary Office, Center for Proper Housing of Ruminants and Pigs, Agroscope, Tänikon 1, CH-8356 Ettenhausen, Switzerland

Published in:

Research in Veterinary Science

Volume 152, 20 December 2022, Pages 333-353

https://doi.org/10.1016/j.rvsc.2022.08.021

Abstract

Observational studies are important in livestock science. As treatment is not assigned randomly in such studies, selection bias can be a problem. This is often addressed by matching methods. However, if treatment and control groups differ considerably in their characteristics, it might be necessary to additionally prune observations that lack overlap in the opposite group. “Matching Frontier” method was developed because pruning observations manually often results in suboptimal solutions. The feasibility of the approach for animal health and welfare issues was tested in an observational study evaluating the effect of free stall housing and increased lying comfort on udder health, veterinary costs, and antibiotic usage in Swiss dairy farming.

Data were collected in a survey with 1835 Swiss dairy farmers (response rate 28.3%). The treatment group (n=179) comprised farmers participating in a voluntary animal welfare program that, in addition to free stall housing, required increased lying comfort. Farmers in the control group (n=229) kept their cows in tie stalls.

Using the Matching Frontier method, treated units were matched to control units based on five confounders. Subsequently, observations were pruned to achieve sufficient balance and overlap between the two groups. The effect of the program on the eight outcome variables was finally estimated using linear regression.

Farmers in the treatment group had a lower incidence of clinical mastitis (–3.66 per 100 cow-years, –25%, $p < 0.05$), a lower incidence of culled cows due to udder health problems (–1.61 per 100 cow-years, –30%, $p < 0.05$), fewer veterinary costs (–42.44 per cow-year, –22%, $p < 0.05$), a lower incidence of total intramammary antibiotic treatments (–15.88 per 100 cow-years, –23%, $p < 0.01$), a lower incidence of intramammary antibiotic treatments for mastitis therapy (–7.83 per 100 cow-years, –32%, $p < 0.01$), and a lower incidence of intramammary antibiotic treatments for dry-cow therapy (–7.83 per 100 cow-years, –21%, $p < 0.05$). No differences were found for the average somatic cell count and the number of cows with a cell count above 150.000.

The results suggest that free stall housing, in combination with increased lying comfort, can have a positive effect on udder health, animal welfare, and the economic situation of the farm. Additionally, fewer antibiotic treatments can be beneficial to public health.

The Matching Frontier method has proven to be a helpful tool that may also have added value for future observational studies in livestock science.

Keywords

Dairy, Mastitis, Veterinary cost, Antibiotic usage, Housing system, Matching

3.1 Introduction

Public concerns about animal welfare and specific production practices in livestock agriculture has increased over the last years (European Commission. Directorate General for Health and Food Safety. and TNS Political & Social., 2015; Ly et al., 2021; Wolf et al., 2016). This also applies to the practice of keeping dairy herds in tie stalls, which are less accepted than free stalls (Robbins et al., 2019; Waldrop and Roosen, 2021). In align with these public values, the Swiss government promotes free stall housing through a voluntary direct payment program. This raises the question of whether the increase in animal welfare can also be shown based on measurable animal health indicators.

In previous studies in Switzerland, positive effects of the voluntary free stall program on lameness, alterations of the skin around the hocks, callosities at the carpal joints, teat injuries, the incidence of medical treatments, and veterinary costs have been found (Odermatt et al., 2018; Regula et al., 2004) So far, one aspect that has limitedly been considered in program evaluations is udder health. However, udder health plays a major role in dairy farming, as udder health problems can lead to great suffering of cows, cause high costs for farmers and are the main reason for antibiotic usage (Halasa et al., 2007; Heikkilä et al., 2012; Menéndez González et al., 2010; Schaeren, 2006). Antibiotic usage in livestock is increasingly being viewed critically because it can provoke antibiotic resistance. This is a threat to public health at the global level (Talebi Bezmin Abadi et al., 2019).

Therefore, the present study has the aim to evaluate the effect of free stall housing on udder health, veterinary costs, and antibiotic usage in Swiss dairy farming.

3.2 Method

3.2.1 Voluntary free stall housing program

Switzerland promoted the system of free stalls through a voluntary program called "Particularly animal friendly stabling" (PAS). Farmers who participated had to keep cows in a free stall housing system as opposed to tie stalls. Also, the program required a lying area separated from feeding area. This had to be bedded with deep straw or must comprise cubicles with an equivalent soft mattress. In the feeding area, solid flooring was mandatory. Farmers received a yearly amount of 90 CHF per livestock unit if they participated in the program (In 2018, one Swiss franc [CHF] corresponded € 0.87 and US $1.02; https://data.snb.ch). In 2018, 31.4% of Swiss dairy farmers participated in the program (FOAG, 2020). The majority of dairy farmers who kept their cows in free stalls participated in the program. Hence, in the analysis, only free stall farms that participated in the program were compared to farms with tie stalls.

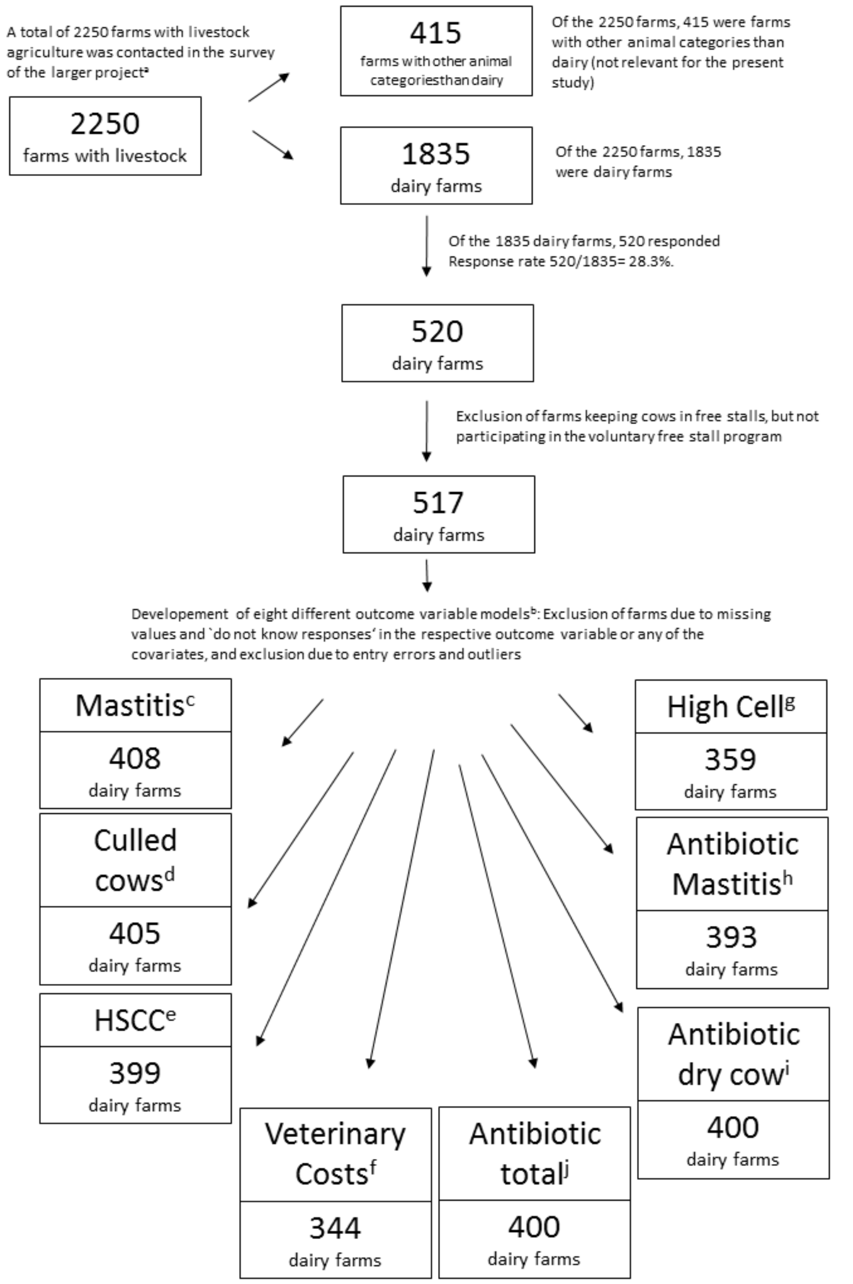
3.2.2 Study design and data collection

In the analysis, a dataset was used generated through a survey in 2019. This survey was not conducted specifically to answer the present research question, but it was part of a larger project aiming at the evaluation of farmers' willingness to participate voluntary antibiotic reduction programs (Swiss National Science

Foundation, 2021). However, data on udder health, antibiotic use and veterinary costs was also collected in the survey, so the data set was appropriate to address the present research question.

In the survey of the larger project, 2250 livestock farms from all over Switzerland were contacted. Of these, 1835 were dairy farms and 415 were farms with other animal categories than dairy (Figure 1). Both the total sample size of 2250 and the division into 1835 dairy farms and 415 farms with animal categories other than dairy was determined based on the research questions of the larger project and were not directly connected to the research question of the present paper. The 1835 dairy farms were randomly drawn from the population of all dairy farms in Switzerland, which comprises 25,007 farms. (FOAG, 2020). The 415 farms with animal categories other than dairy do not play a role in the further progress of this paper.

Ch.3 Figure 1. The path from the 2250 farms contacted in the survey to the final samples of the outcome variable models



[a] The larger project evaluated farmers' willingness to participate in voluntary antibiotic reduction programs. For more information, please see http://www.nfp72.ch/en/projects/module-3-optimised-use-of-antibiotics/providing-the-right-incentives (accessed 20 June 2021). The sample size of 2250 was determined on the base of the research question of the larger project.

[b] An outcome variable model was a regression model with a dependent outcome variable and the independent covariates. Not all of the 517 farms provided data on all variables, so the number of farms differed among the models.

[c] Incidence of clinical mastitis in 2018

[d] Incidence of culled cows due to udder health problems in 2018

[e] Average Herd somatic cell count throughout 2018

[f] Cumulative veterinary costs for dairy cows throughout 2018

[g] Number of cows with somatic cell count above 150.000 at least once in 2018

[h] Incidence of antibiotic treatments for mastitis therapy in 2018

[i] Incidence of antibiotic treatments for dry-cow therapy in 2018

[j] Incidence of total intramammary antibiotic treatments in 2018

3.2.3 Questionnaire

The questionnaire used in this study included 43 questions on 12 DINA4 pages. It was initially developed in German and translated into French and Italian for the non-German-speaking regions with the help of a professional translation service provider. The questionnaire was pretested with five veterinarians and 15 farmers. Fifteen questions from the questionnaire were relevant to this study. These are presented in Table 1. Farmers were asked to base all their responses in the survey exclusively on the year 2018.

Ch.3 Table 1. Variables collected in the survey

Variable	Description
Mastitis	Incidence of clinical mastitis in 2018
Culled cows	Incidence of culled cows due to udder health problems in 2018
HSCC	Average Herd somatic cell count throughout 2018
High cell	Number of cows with somatic cell count above 150.000 at least once in 2018
Veterinary costs	Cumulative veterinary costs for dairy cows throughout 2018
Insemination costs	Amount of total veterinary costs spent on insemination
Antibiotic mastitis	Incidence of antibiotic treatments for mastitis therapy in 2018
Antibiotic dry-cow	Incidence of antibiotic treatments for dry-cow therapy in 2018
Free stall program	Dummy for whether farm took part in the voluntary free stall housing program “Particularly animal friendly stabling” (PAS) in the year 2018
Housing system	Dummy for whether farms keep their cows in a free stall housing system
Number of cows	Average number of cows on farm throughout 2018
Milk production	Average level of yearly milk yield per cow
Organic farming	Dummy for whether farm was organic
Outdoor program	Dummy for whether farm took part in the voluntary animal welfare program “Regular outdoor access of livestock” (ROEL) in 2018
Grassland program	Dummy for whether farm took part in the voluntary “Grassland-based milk and meat program” (GMF) in 2018
Agricultural zone	Agricultural zone in which farm is placed (plain zone, hill zone, and mountain zone)
Agricultural education	Farmer’s level of agricultural education

Outcome variables collected through the survey include the incidence of clinical mastitis (“Mastitis”), the incidence of culled cows due to udder health problems (“Culled cows”), average herd somatic cell count over the year 2018 (“HSCC”), the number of cows with a somatic cell count level above 150.000—at least once during 2018 (“High cell”), cumulative veterinary costs (“Veterinary costs”), the incidence of intramammary antibiotic treatments for mastitis therapy (“Antibiotic mastitis”), and the incidence of antibiotic treatments for dry-cow therapy (“Antibiotic dry-cow”).

The treatment variable of interest is whether farmers participated in the voluntary free stall program in 2018 (“Free stall program”). Furthermore, farm and farmer characteristics were collected in the survey. As it is possible to keep cows in free stalls without participating in the voluntary free stall program, farmers were additionally asked about the housing system (“Housing system”). Further questions related to the number of cows on farm (“Number of cows”), the average level of milk production per cow and year (“Milk production”), and whether the farm was conventional or organic (“Organic farming”). In Switzerland, different agricultural zones (plain zone, hilly zone, and mountain zone) were distinguished according to altitude and geographical conditions (“Agricultural zone”). Besides the free stall program, there are two other voluntary programs in Switzerland. One promotes regular outdoor access to livestock (“Outdoor program”). Farms participating in this program must give their animals access to pasture or an outdoor run for a minimum period per year. The other program promotes grassland-based production of milk and meat (“Grassland program”). For participating farms in the plain zone and hilly zone, 75% of the feed ration must be roughage, while 85% must be roughage for farms in the mountain zone. Program participation is therefore a feasible indicator of the feeding regime on the farm. Finally, farmers were asked about their level of agricultural education (“Agricultural education”).

3.2.4 Data processing

Data collected through the survey was processed for further use. In all outcome variables, farmers had the option to check a “don’t know” option. Because these responses were not considered in the statistical analysis, they were replaced by missing values.

The farm was the unit of the analysis. The within-herd incidences of clinical mastitis, culled cows, and intramammary antibiotic treatments were calculated as the number of reported cases or treatments reported by the farmer in 2018 divided by the average number of cows per farm throughout 2018 and expressed per 100 cows and year. Subsequently, for every farm, treatment incidence for mastitis therapy was added to the incidence of treatments for dry-cow therapy to obtain the incidence of total intramammary antibiotic treatments (“Antibiotic total”).

For veterinary costs, the costs of insemination charged using the veterinarian were first subtracted from total veterinary costs and divided by the average number of cows per farm.

Finally, implausible values (entry errors) and values that deviated very strongly from the other values (outliers) were removed from the dataset.

3.2.5 Matching frontier method and statistical analysis

The decision to keep dairy cows in either a free stall or a tie stall is not random. It is influenced by the characteristics of the farmer and the farm. Estimated treatment effects could therefore be biased due to observed and unobserved confounding factors (Gelman et al., 2020). This is a common problem in observational studies. Remedies include methods that assume conditional independence (Imbens and Wooldridge, 2009). Under this assumption, unbiased estimates can be obtained after controlling for observed characteristics (Kreif et al., 2016). This can be done using parametric regression, but in situations with unbalanced groups, the estimated treatment effects can be highly sensitive to the choice of the parametric model specification (Ho et al., 2007). To tackle this problem, data can be pre-processed with the aim of gaining more balance and overlap between the two groups. This reduces model dependence and bias in subsequent regression (Ho et al., 2007). For this purpose, a matching method is suitable. In doing so, a treated observation is matched with one or more observations from the control group that are similar in characteristics. However, if there are observations in one of the groups that have no counterpart in the other group, balance can only be considerably achieved. A solution to this is the pruning of these observations from the dataset at the cost of reducing sample size. Therefore, a trade-off must be made between keeping observations while accepting some imbalance and pruning observations while achieving higher balance. In recent decades, several matching methods have been developed that have addressed this issue differently. These methods either try to reduce imbalance for a given sample size (e.g., Mahalinobis or Propensity score matching), fix balance and maximize sample size (e.g., Coarsened exact matching), or are arbitrary compromises between the two (such as calipers with ad hoc thresholds applied to other methods) (King et al., 2017). Since none of these methods optimize for both, researchers must settle for suboptimal solutions or manually optimize by iteratively tweaking their matching method and rechecking imbalance (King et al., 2017). The second approach is time-intensive. Moreover, it does not guarantee that an optimal solution is found.

To overcome the weaknesses of the manual approach, King et al. (2017) developed a procedure classified as a machine-learning approach (Sizemore and Alkurdi, 2019). Using this procedure, researchers can define, estimate, and visualize the Matching Frontier. The Matching Frontier comprises a set of matched subsamples that characterizes the trade-off between imbalance and sample. For each possible sample size, an algorithm is used to determine the matching solution with the lowest imbalance. All datasets on this frontier are optimal, meaning that there exists no matching solution with a lower imbalance for a given sample size or a higher sample size for a fixed imbalance. From this frontier, researchers can select one or more data subsets that reflect their preferences regarding imbalance and sample size for subsequent analysis (King et al., 2017).

To estimate the frontier in this study, the R package “MatchingFrontier” was used (King et al., 2015). The algorithm is based on a nearest-neighbor-approach. In a first step, every observation from the treated group is matched to the nearest observation in the control group, where the distance between observations is measured regarding the Mahalanobis distance. A matching with replacement approach was chosen, and the ratio of treated to control units was allowed to vary throughout the matched dataset. This is reflected in the assignment of weights[1] to the control units, which must be accounted for in the subsequent analysis steps. To obtain a sense of how much balance is achieved by this initial matching, the average Mahalanobis imbalance (AMI) metric is calculated. That is the Mahalanobis distance between each unit in the treatment group and the closest unit in the control group averaged over all units (King et al., 2017). In the next step of the algorithm, the unit or units with the largest difference from its matched partner gets pruned. To see how much balance is gained by pruning, the AMI is recalculated. This process is repeated until no imbalance between the treatment and control groups remains and the AMI equals zero. The various subsamples created by this process constitute the Matching Frontier. The Matching Frontier can be visualized by plotting the AMI of these subsamples as a function of the remaining sample size (or the number of observations pruned). After constructing and visualizing the frontier, researchers can select one or more datasets from the frontier that reflect their preference regarding the remaining imbalance and sample size. This selection can be made, for example, on the basis of AMI. However, in the literature, the standardized mean difference in the confounders between the treatment and control groups is more often used to measure the

[1] When the ratio of treated to control unit is not allowed to vary throughout the matched data set (fixed-ratio matching), the sample average treatment effect can be estimated by a simple difference in means between the treated and control group (King et al., 2017). However, in variable-ratio matching, the approach we relied on in our analysis, treatment effects must first be estimated within each matched stratum by a simple difference in means. Aggregating up to the sample average treatment effect requires weighting, with the stratum-level treatment effect weighted according to the number of treated units (King et al., 2017). For further explanation of these weights and their calculation please see (King et al., 2017) and j.mp/CEM

imbalance (Stuart, 2010). A maximum level of 0.1 is usually given as an acceptable cutoff value (Stuart, 2010), which we adopted in this study.

Based on the selected dataset, the treatment effect got estimated. We were interested in the average treatment effect on the treated (ATT). However, as it was not possible to achieve sufficient balance without pruning observations from the treatment group, the remaining observations were not representative of all treated units in the population. Therefore, the estimand was the average treatment effect in the remaining matched sample (ATM) (Greifer, 2021a) or sometimes called the feasible sample average treatment effect on the treated (FSATT) (King et al., 2017). The effect was estimated through a linear regression in which, in addition to the treatment variable, the confounders were included as control variables. This follows the common recommendation to run a regression after matching to account for the remaining imbalance (Abadie and Imbens, 2006; Rubin, 1973; Rubin and Thomas, 2000). The regression also included the weights that came from matching with replacement.

Estimated standard errors for the treatment effect have to consider the uncertainty present in the analysis through matching and estimation of the treatment effect (Greifer, 2021b). Overall, there are no analytic solutions to these issues; most studies have been done on uncertainty estimation after matching has relied on simulation studies. These have shown that robust standard errors and, depending on the matching method, cluster-robust standard errors were valid after matching (Austin, 2013, 2009; Austin and Small, 2014; Gayat et al., 2012; Wan, 2019) and tend to be conservative in situations with continuous outcomes (Hill and Reiter, 2006). The treatment effect and robust standard errors were estimated using the R packages “lmtest” (Zeileis and Hothorn, 2002) and “sandwich” (Zeileis, 2004).

The described steps with determination of the Matching Frontier, selection of a dataset, and calculation of the treatment effects were performed separately for each outcome variable. Overall, eight different models were calculated. Matching of these eight models was performed in the first step on the basis of the five confounders “Number of cows”, “Milk production”, “Organic farming”, “Outdoor program”, and “Grassland program”. These five confounders were, in addition to the treatment variable “Free stall program”, also included as independent variables in the linear regression. Subsequently, this solution was compared with a matching based on all seven covariates (including “Agricultural zone” and “Agricultural education”).

3.3 Results

3.3.1 Descriptive Results

Figure 1 shows the path from the initially 1835 dairy farms contacted in the survey to the final outcome variable models used for the analysis. Of the 1835 dairy farms, 520 responded. This corresponds to a return rate of 28.3% (= 520/1835). From these, three farmers reported keeping cows in free stalls but not participating in the voluntary free stall program. Since these fit neither into the treatment nor into the control group, these were dropped from the dataset.

The remaining 517 farms were then used as a starting point to develop the 8 linear regression models with different outcomes. These linear regression models each consist of a dependent outcome variable and the independent covariates. In each model, only those farms were included that had no missing values or do not know answers, outliers and entry errors in the specific outcome variable and all covariates. Thus, the number of farms differed slightly in the different models (Figure 1). The total number of farms ranged from 359 to 408, depending on the outcome model. The number of farms with free stalls ranged from 152 to 179, and for tie stalls from 188 to 229 (Table 2). Table 2 provides the summary statistics for the outcome variables. Histograms for all outcome variables can be found in Appendix A.

Ch.3 Table 2. Summary statistics of outcome variables

Variable	Unit	Treatment group	N	Mean	SD	Median	Min	Max
Mastitis[a]	per 100 cow-years	Free stall	179	11.00	7.54	9.43	0	46.67
		Tie stall	229	14.53	10.59	13.33	0	66.67
		Free stall and tie stall	408	12.98	9.53	11.54	0	66.67
Culled cows[b]	per 100 cow-years	Free stall	178	3.49	3.87	2.63	0	20.00
		Tie stall	227	5.03	6.41	3.85	0	38.46
		Free stall and tie stall	405	4.35	5.49	2.86	0	38.46

HSCC[c]	1000 cells/ml	Free stall	179	108.65	38.03	100.00	24	240.00
		Tie stall	220	90.97	39.06	82.50	20	300.00
		Free stall and tie stall	399	98.90	39.54	90.00	20	300.00
High cell[d]	per 100 cow-years	Free stall	152	33.67	21.15	28.57	0	100.00
		Tie stall	207	30.91	18.42	28.57	0	100.00
		Free stall and tie stall	359	32.08	19.64	28.57	0	100.00
Veterinary costs[e]	Francs per cow-year	Free stall	156	150.67	101.38	133.05	0	625.00
		Tie stall	188	195.70	133.67	190.08	0	733.33

		Free stall and tie stall	344	175.28	122.03	151.00	0	733.33
Antibiotic mastitis[f]	per 100 cow-years	Free stall	171	17.14	16.00	12.50	0	102.50
		Tie stall	222	22.53	23.21	20.00	0	238.10
		Free stall and tie stall	393	20.19	20.54	16.67	0	238.10
Antibiotic dry-cow[g]	per 100 cow-years	Free stall	177	34.98	31.11	27.50	0	100.00
		Tie stall	223	37.07	32.53	29.41	0	100.00
		Free stall and tie stall	400	36.15	31.88	28.57	0	100.00

Antibiotic total[h]	per 100 cow-years	Free stall	166	53.00	37.83	48.58	0	170.00
		Tie stall	215	58.82	39.87	54.17	0	190.91
		Free stall and tie stall	381	56.29	39.05	51.67	0	190.91

[a] Incidence of clinical mastitis in 2018

[b] Incidence of culled cows due to udder health problems in 2018

[c] Average Herd somatic cell count throughout 2018

[d] Number of cows with somatic cell count above 150.000 at least once in 2018

[e] Cumulative veterinary costs for dairy cows throughout 2018

[f] Incidence of antibiotic treatments for mastitis therapy in 2018

[g] Incidence of antibiotic treatments for dry-cow therapy in 2018

[h] incidence of total intramammary antibiotic treatments in 2018

For covariates, Tables 3–5 provide summary statistics. Numbers are presented as an example for the model where “Incidence of clinical mastitis” was the outcome. Numbers for the other 7 outcome models can be found in Appendix B, Appendix C, and Appendix D. As can be seen, the numbers for the covariates in the different models differ only minimally. Covariates are represented separately for the treatment and control group. T-tests were conducted to check whether the differences in the group was statistically different. Treatment farms had almost twice as many cows. Additionally, treatment farms had a significantly higher milk yield per cow and year. The treatment group had a higher proportion of farms located in the plain zone and a higher share of farms taking part in the outdoor exercise program. Farmers with tie stalls tended to participate more frequently in the grassland program. On the average, farmers with free stalls were higher educated.

Ch.3 Table 3. Summary statistics of continues covariate from treatment group ("Free stall") and control group ("Tie stall") and result of t-test to check for statistical significance of mean difference. Numbers are shown for the model where "Incidence of clinical mastitis" was the outcome variable. Numbers for the other 7 outcome models can be found in Appendix B.

Variable	Treatment group	Number of farms	Mean	SD	Median	Min	Max	t-value (p-value)
Number of cows	Free stall	179	37.06	18.57	35	4	92	-12.42
	Tie stall	229	18.64	7.88	18	3	45	(0.000)

Ch.3 Table 4. Summary statistics of dummy covariates from treatment group ("Free stall") and control group ("Tie stall") and result of t-test to check for statistical significance of mean difference. The percentage reflects the proportion of organic farms and the proportion of participants in the outdoor and grassland program in the respective group. Numbers are shown for the model where "Incidence of clinical mastitis" was the outcome variable. Numbers for the other 7 outcome models can be found in Appendix C.

Variable	Treatment group	Number of farms	%	t-value (p-value)
Organic farming	Free stall	179	18.2%	−1.47 (0.142)
	Tie stall	229	12.9%	
Outdoor program[a]	Free stall	179	93.1%	−2.95 (0.003)
	Tie stall	229	83.5%	
Grassland program[b]	Free stall	179	66.5%	2.80 (0.005)
	Tie stall	229	79.9%	

[a] Farms participating in the outdoor program must give their animals access to pasture or an outdoor run for a minimum period per year. For more detailed information please see Odermatt (2018)

[b] For participating farms in the plain zone and hilly zone, 75% of the feed ration must be roughage, while 85% must be roughage for farms in the mountain zone.

Ch.3 Table 5. Summary statistics of categorical covariates from treatment group ("Free stall") and control group ("Tie stall"). To illustrate the differences between the groups, means based on categorical numbering of variables were calculated. A t-test was used to determine whether the difference between the means was statistically significant. Numbers are shown for the model where "Incidence of clinical mastitis" was the outcome variable. Numbers for the other 7 outcome models can be found in Appendix D.

Variable	Treatment group	Description	%	Mean[a]	t-value (p-value)
Milk production[b]	Free stall (n=179)	1 "< 5.000"	3.4%	4.02	–5.83 (0.000)
		2 "5.000-6.000"	11.2%		
		3 "6.001-7.000"	22.3%		
		4 "7.001-8.000"	27.4%		
		5 "8.001-9.000"	20.1%		
		6 "9.001-10.000"	10.1%		
		7 ">10.000"	5.6%		
	Tie stall (n=229)	1 "< 5.000"	5.2%	3.23	
		2 "5.000–6.000"	27.5%		
		3 "6.001–7.000"	27.5%		
		4 "7.001–8.000"	24.0%		
		5 "8.001–9.000"	11.4%		
		6 "9.001–10.000"	3.5%		

		7 " > 10.000"	0.9%		
Agricultural zone[c]	Free stall	1 Plain zone	51.4%	2.06	5.19 (0.000)
		2 Hilly zone	21.1%		
		3 Mountain zone I	8.6%		
		4 Mountain zone II	9.7%		
		5 Mountain zone III	6.9%		
		6 Mountain zone IV	2.3%		
	Tie stall	1 Plain zone	26.7%	2.81	
		2 Hilly zone	14.5%		
		3 Mountain zone I	26.2%		
		4 Mountain zone II	20.4%		
		5 Mountain zone III	8.1%		
		6 Mountain zone IV	4.1%		
	Free stall	1 None	2.8%	4.07	
		2 VET certificate[e]	4.5%		
		3 VET diploma[f]	33.0%		
		4 Diploma of higher education[g]	16.8%		

		5 Advanced diploma[h]	34.6%		
		6 College[i]	2.8%		
		7 University[j]	5.6%		
Agricultural education[d]					–4.25 (0.000)
	Tie stall	1 None	3.9%	3.54	
		2 VET certificate[e]	4.8%		
		3 VET diploma[f]	51.5%		
		4 Diploma of higher education[g]	18.3%		
		5 Advanced diploma[h]	18.3%		
		6 College[i]	0.4%		
		7 University[j]	2.6%		

[a] To calculate the mean, categorical numbering was used (1–7 for “Milk production” and” Agricultural education”, 1–6 for “Agricultural zone”)

[b] Average level of yearly milk yield per cow

[c] Agricultural zone in which farm is placed (plain zone, hill zone, and mountain zone)

[d] Farmer’s agricultural education level. For further information on the Swiss educational system, please see https://www.edk.ch/en/education-system/diagram

[e] Federal vocational education and training (apprenticeship) certificate

[f] Federal vocational education and training (apprenticeship) diploma

[g] Federal diploma of higher education

[h] Advanced federal diploma of higher education

[i] College of higher education

[j] University incl. federal institute of technology /University of applied sciences

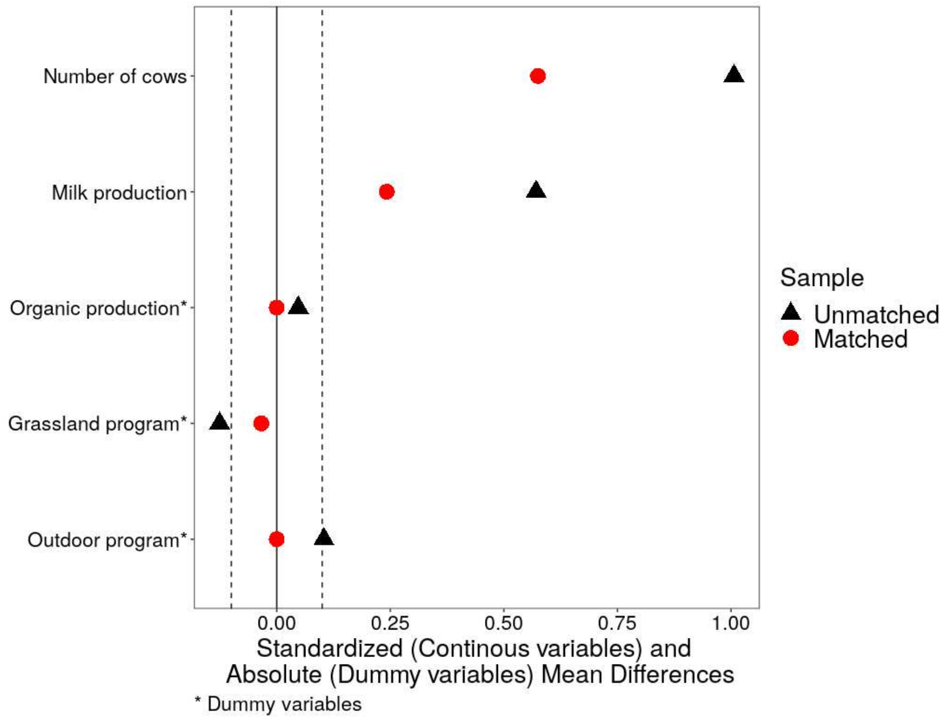
3.3.2 Matching Frontier and treatment effects

Intermediate steps of the analysis are shown by the example of the "Antibiotic dry-cow" model. For each of the other seven models, only treatment effects are represented. Intermediate results of these were almost identical, since the same confounders were used in all models. The only minimal differences were due to different structures in missing values.

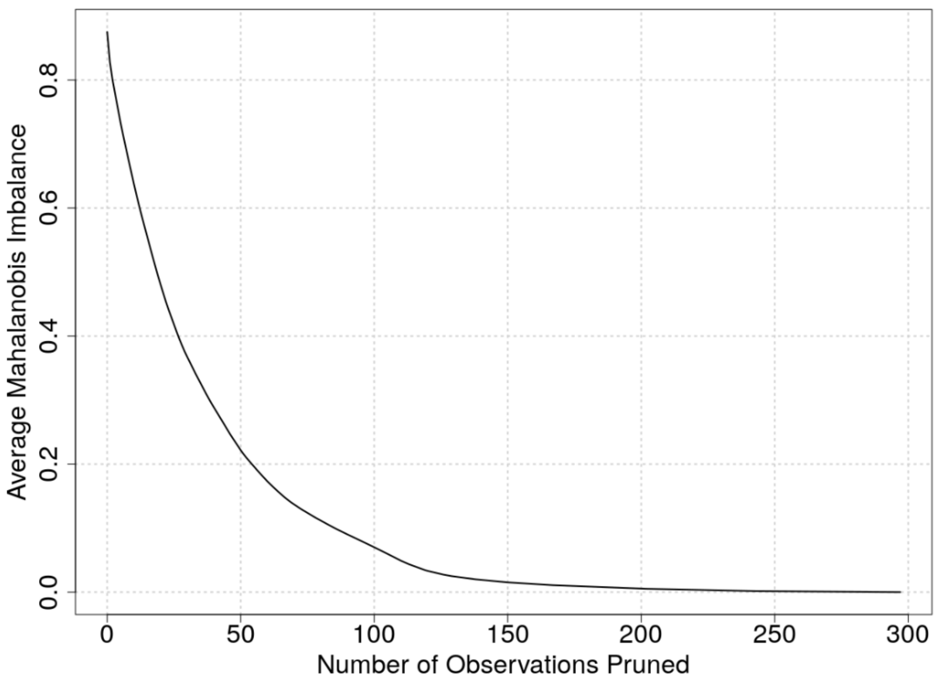
Results are first represented for the matching solution based on five confounders. Afterward, they were compared to the seven confounder cases.

In the first step of the analysis, treatment units were matched to control units. This already reduced the imbalance between the treatment and control group (Figure 2). Before matching, the absolute mean difference in the two dummy variables "Organic farming" and "Outdoor program" had already been low (0.05 and 0.10, respectively). After matching, they were perfectly balanced. The absolute mean difference in the variable "Grassland program" decreased from 0.13 to 0.03. The imbalance in "Number of cows" regarding standardized mean difference was clearly reduced from 1.01 to 0.58. However, the value was still well above the cut-off value of 0.1. This also applies to the variable "Milk production" (from 0.57 to 0.24). To achieve further balance between the two groups, observations were pruned. Figure 3 illustrates the corresponding Matching Frontier. Before observations were pruned, the AMI was 0.8. By removing a few observations, much could be gained regarding balance. If 50 observations were removed, the AMI was reduced to 0.2. From 150 pruned observations, the imbalance was close to zero. The AMI is a measure of total imbalance regarding all covariates. Additionally, Figure 4 shows the course of the mean differences of the individual covariates. Covariates “Organic farming” and “Outdoor program” remained perfectly balanced throughout the pruning process. After a few pruned observations, the covariate “Grassland program” was also balanced. From 51 pruned observations, the covariate “Milk production” is below the cut-off value of 0.1. The covariate “Number of cows” reached this point at 117 pruned observations. Based on Figures 3 and 4, a dataset was subsequently selected. The two extremes, either the full sample or a perfectly balanced sample, would both be accompanied by major disadvantages. The former would forgo the reduction in imbalance that can be observed after only a few pruned observations. For the latter, the remaining number of observations would be small, resulting in a large variance of the treatment effect. Therefore, the dataset was selected in which the standardized mean difference for all covariates is below the cut-off value of 0.1. Depending on the outcome variable model, the number of observations that had to be pruned to reach a value below 0.1 in standardized mean difference, differed. It lied between 100 and 119 pruned observations (Table 6). Based on these datasets, the treatment effect was then calculated using linear regression, including the respective outcome variable model as depend variable and the treatment variable "Free stall program" and the five confounders "Number of cows", "Milk production", "Organic farming", "Outdoor program", and "Grassland program" as independent variable.

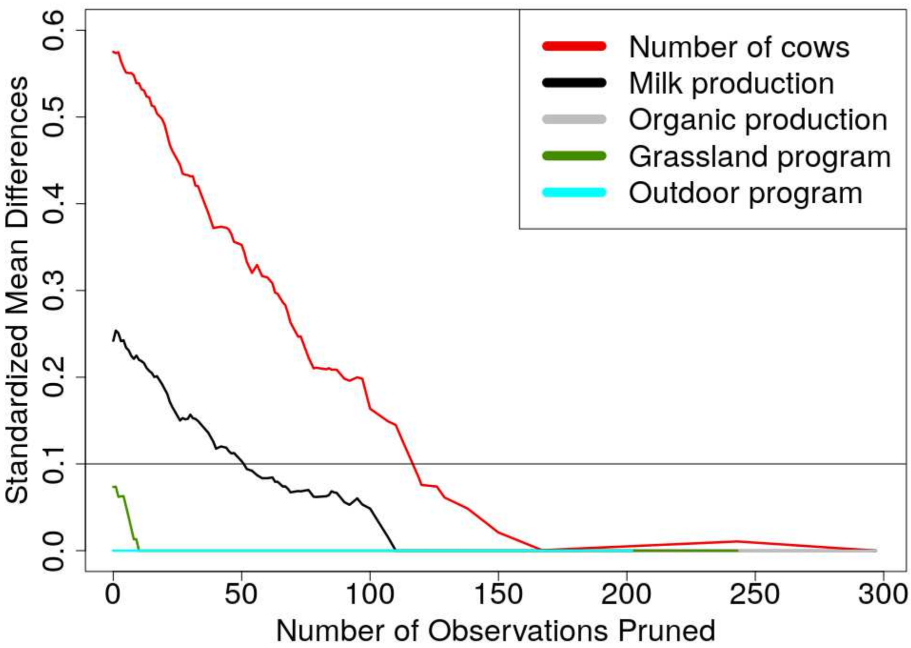
Ch.3 Figure 2. Mean differences of covariates before (black triangle) and after matching (red dots). Results are shown for model with outcome variable "incidence of antibiotic treatments for dry-cow therapy". Standardized mean difference for continuous variables was calculated dividing mean differences by standard deviation of the treated group. In case of dummy variables, absolute mean differences are displayed.



Ch.3 Figure 3. Matching Frontier of outcome variable model "Incidence of antibiotic treatments for dry-cow therapy". The Matching Frontier comprises a set of matched subsamples that characterizes the trade-off between imbalance and sample size. For each possible sample size, an algorithm is used to determine the matching solution with the lowest imbalance. All datasets on this frontier are optimal, meaning that there exists no matching solution with a lower imbalance for a given sample size or a higher sample size for a fixed imbalance. Imbalance was measured by average Mahalanobis imbalance (AMI) metric, that is the Mahalanobis distance between each unit in the treatment group and the closest unit in the control group averaged over all units



Ch.3 Figure 4. Standardized mean differences of five confounders along the Matching Frontier. Results are shown for model with outcome variable "incidence of antibiotic treatments for dry-cow therapy". Standardized mean difference was calculated dividing mean differences by standard deviation of the treated group.



The resulting coefficients of the free stall program of all eight models are displayed in Table 6. Full model results of all regression models including estimated coefficients of the five confounders can be found in Appendix E. To check that assumptions of linear regression (e.g. linearity and homoscedasticity) were fulfilled, fitted values and residuals were visually inspected. We additionally addressed a potential problem of heteroscedasticity by relying on robust standard errors.

Treatment effects were significant at the 5% level for incidence of clinical mastitis (–3.66 per 100 cow-years), incidence of culled cows (–1.61 per 100 cow-years), veterinary costs (–42.44 per cow-year), and incidences of antibiotic treatments for dry-cow therapy (–8.70 per 100 cow-years). Incidence of antibiotic treatments for mastitis therapy (–7.83 per 100 cow-years) and the incidence of total intramammary antibiotic treatments (–15.88 per 100 cow-years) were significant at the 1%-level. No effect could be found for average herd somatic cell count and number of cows with somatic cell count level above 150.000.

The results presented in Table 6 were calculated based on one dataset selected from the Matching Frontier. However, it is also possible to calculate and visualize the treatment effect along the entire Matching Frontier. This allows us to see how the treatment effects change with increasing balance, which is shown for the "Antibiotic dry-cow" model in Figure 5. With increasing balance, the treatment effects decreased. An estimate based on the complete sample would thus overestimate the treatment effect. Additionally, the 90% confidence intervals are plotted, which increased with decreasing sample size. Figure 6 again shows the same treatment effects. However, here, the model dependence, calculated according to Athey and Imbens (2015) (Athey and Imbens, 2015), is additionally plotted. It can be seen that the model dependence decreased with increasing balance.

Ch.3 Table 6. Treatment effects of free stall program on outcome variables after matching and pruning observations. The treatment effects were determined using 8 different linear regressions. The dependent variable was the corresponding outcome variable, independent variables were the treatment variable "Free stall program" and the five confounders "Number of cows", "Milk production", "Organic farming", "Outdoor program", and "Grassland program". Linear regression was performed in each case with the largest possible sample at which all confounders at the same time had a maximum standardized mean difference of 0.1. In addition, means of treatment group ("Free stall") and control group ("Tie stall") robust standard errors, t-value and p-value of statistical significance of treatment effect were displayed. For statistically significant treatment effects, the difference in percentage between treated and control group is reported. Full model results of all regression models including estimated coefficients of the five confounders can be found in Appendix E.

Outcome variable	Number of observations pruned	Remaining number of observations included in linear regression	Treatment group	Means after matching and pruning	Treatment effect of free stall program	% Difference	Robust standard error	t-value	p-value
Mastitis[a]	100	308	Free stall	11.16	–3.66*	–25%	1.69	–2.16	0.031
			Tie stall	14.80					
Culled cows[b]	101	304	Free stall	3.69	–1.61*	–30%	0.66	–2.42	0.016
			Tie stall	5.33					

HSCC[c]	111	288	Free stall	97.95	8.37		5.57	1.50	0.134
			Tie stall	88.93					
High cell[d]	118	241	Free stall	30.82	–0.91		3.26	–0.28	0.781
			Tie stall	31.32					
Veterinary costs[e]	119	225	Free stall	152.86	–42.44*	–22%	17.94	–2.37	0.019
			Tie stall	197.06					
Antibiotic mastitis[f]	103	290	Free stall	16.52	–7.83**	–32%	2.39	–3.28	0.001
			Tie stall	24.25					

Antibiotic dry-cow[g]	117	283	Free stall	33.50	–8.80*	–21%	4.35	–2.02	(0.044)
			Tie stall	41.89					
Antibiotic total[h]	111	270	Free stall	50.37	–15.88**	–23%	4.99	–3.18	0.002
			Tie stall	65.71					

Levels of significance: *$p < 0.05$; **$p < 0.01$

[a] Incidence of clinical mastitis in 2018

[b] Incidence of culled cows due to udder health problems in 2018

[c] Average Herd somatic cell count throughout 2018

[d] Number of cows with somatic cell count above 150.000 at least once in 2018

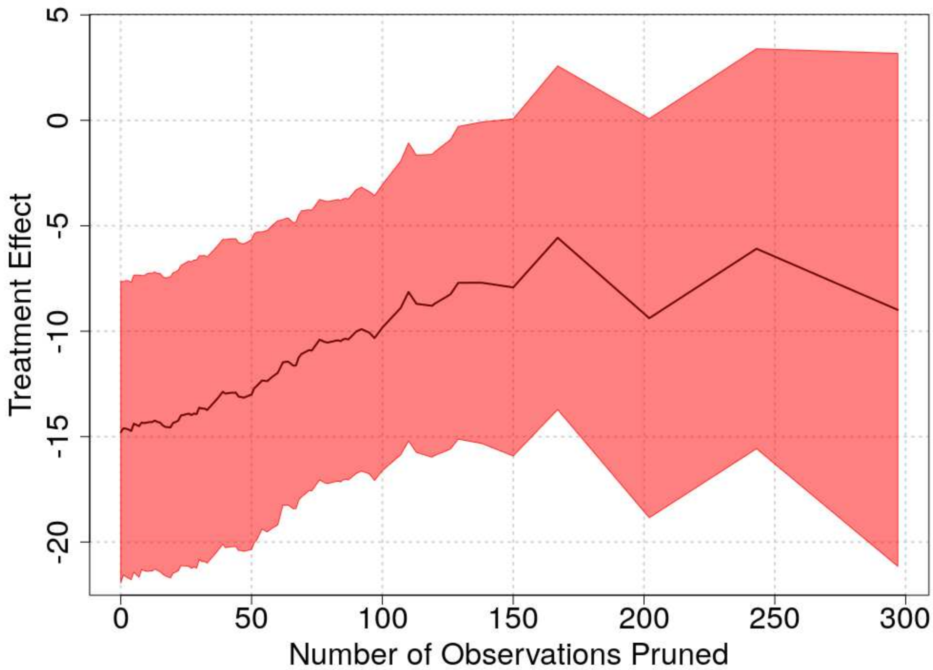
[e] Cumulative veterinary costs for dairy cows throughout 2018

[f] Incidence of antibiotic treatments for mastitis therapy in 2018

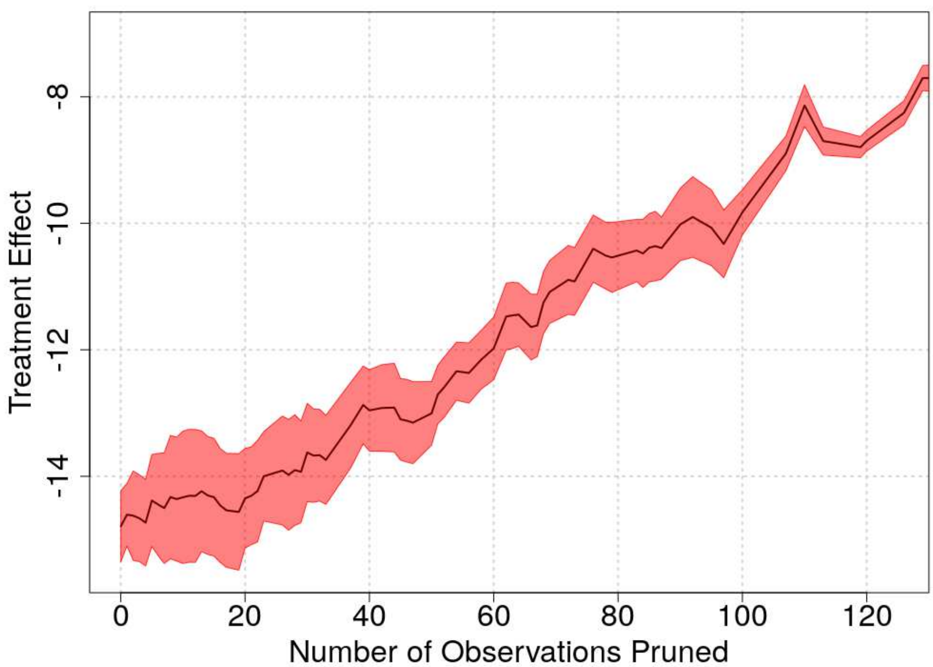
[g] Incidence of antibiotic treatments for dry-cow therapy in 2018

[h] incidence of total intramammary antibiotic treatments in 2018

Ch.3 Figure 5. Treatment effect of free stall program on incidence of antibiotic treatments for dry-cow therapy (per 100 cow-years) and 90%-confidence interval along the Matching Frontier

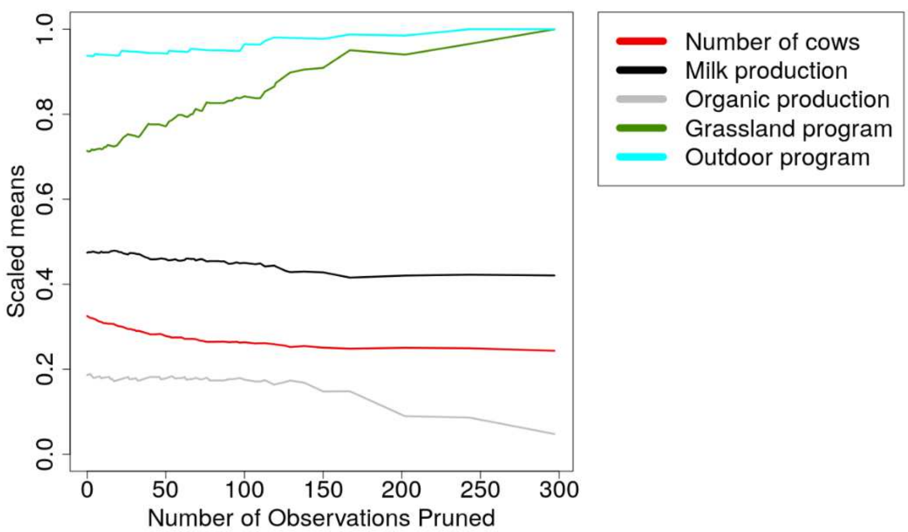


Ch.3 Figure 6. Treatment effect of free stall program on incidence of antibiotic treatments for dry-cow therapy (per 100 cow-years) and model dependence according to Athey and Imbens (2015) along the Matching Frontier



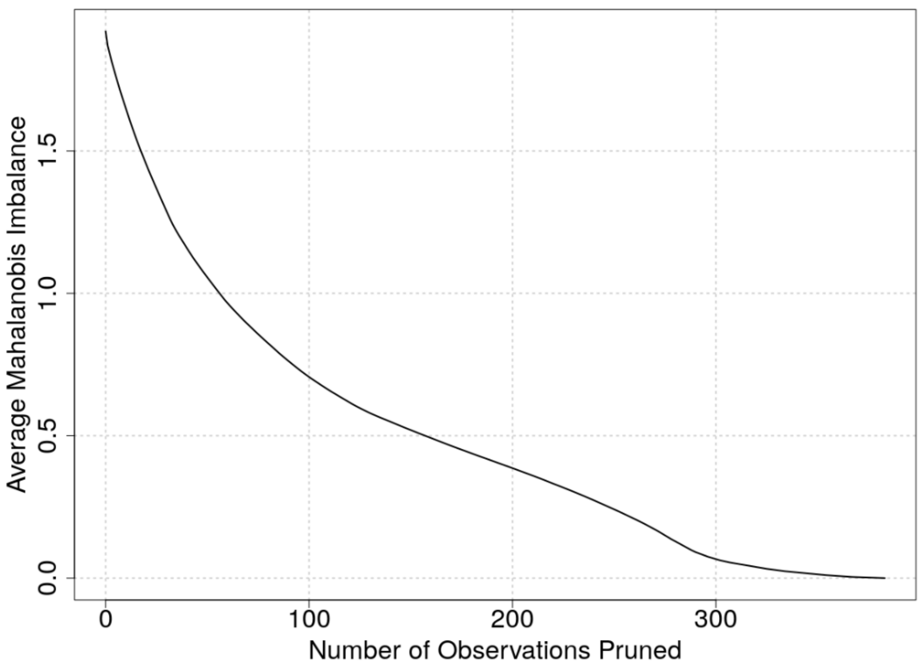
Pruning of observations changes the quantity of interest. This is shown in Figure 7, where the scaled covariate means of all remaining farms in the sample are plotted as a function of the number of observations pruned. The pruning decreased the average number of cows and the milk yield along the Matching Frontier. The reason for this is that large free stall farms with high milk production levels were pruned first. In the full sample, the maximum number of cows was 150 cows, and with 117 pruned observations, it was only 53 cows. In the case of the covariate "Grassland program", the proportion of farms not participating in the program decreased significantly. This was also true for the outdoor program. Due to the change in the quantity of interest, found effects can therefore no longer be applied to all farms in the treatment group. For example, the eight treatment effects found above cannot be generalized to free stall farms having more than 53 cows.

Ch.3 Figure 7. Covariate Means along the Matching Frontier. Results are shown for model with outcome variable "incidence of antibiotic treatments for dry-cow therapy"

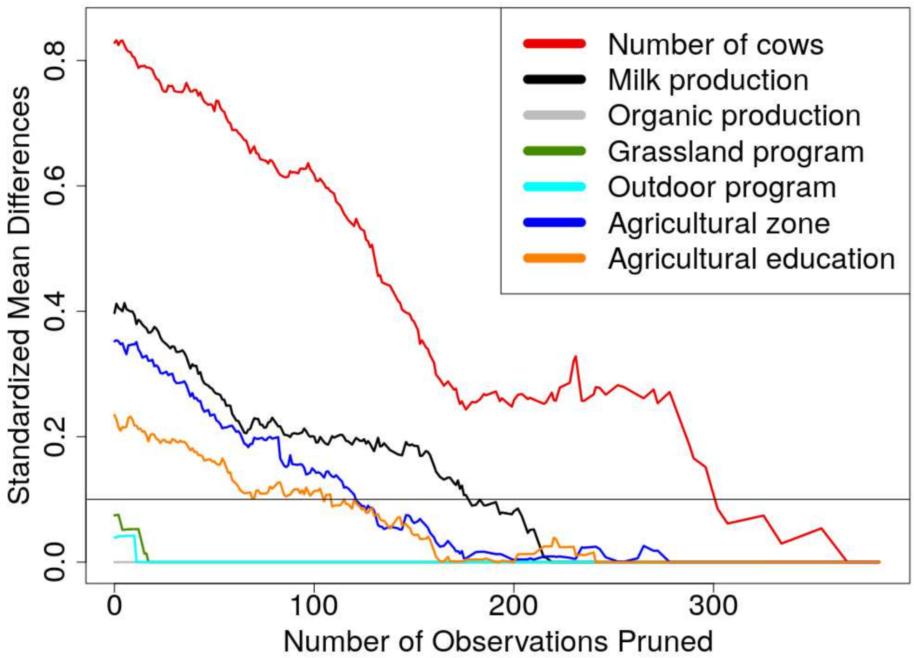


Finally, matching based on five confounders is compared with matching based on seven confounders, including covariates “Agricultural zone” and “Agricultural education.” The corresponding Matching Frontier and mean covariate plots are shown in Figures 8 and 9. The AMI is higher along the entire frontier than in the five confounder case. Only with 300 pruned observations are all standardized mean differences below the cut-off of 0.1. This situation is unsatisfactory. Therefore, it was examined whether the matching based on five confounders is not advantageous overall, also regarding the two covariates “Agricultural zone” and “Agricultural education.” For this purpose, the standardized mean differences from the matching based on five confounders are shown again in Figure 10. Additionally, the mean differences for the two covariates “Agricultural zone” and “Agricultural education” are plotted, which were not included in the matching. As expected, these two covariates are not perfectly balanced. However, due to the matching based on the other five confounders and pruning of observations, the imbalance in these two covariates was also lower than in the unmatched full sample. At 115 pruned observations, all seven covariates are below or close to the cut-off value of 0.1 regarding standardized mean difference. The five confounder solution thus seems to have an advantage over the seven confounder solution, also regarding the variables “Agricultural zone” and “Agricultural education.” Significantly fewer pruned observations are sufficient to achieve a reasonable balance. Since the five confounder solution was more advantageous than the seven confounder solution, the treatment effects were not recalculated.

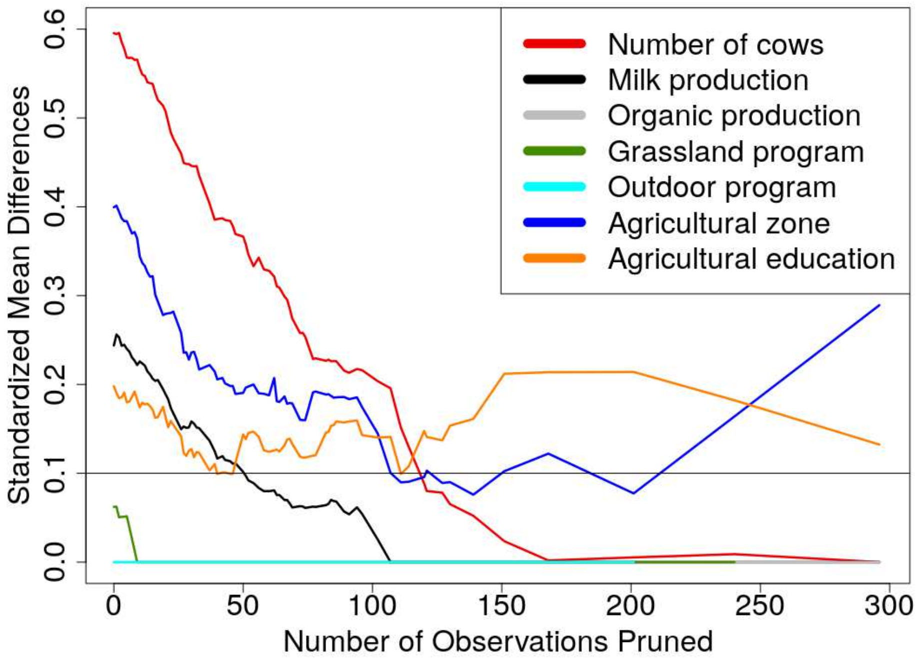
Ch.3 Figure 8. Matching Frontier for matching based on seven confounders. The Matching Frontier comprises a set of matched subsamples that characterizes the trade-off between imbalance and sample size. For each possible sample size, an algorithm is used to determine the matching solution with the lowest imbalance. All datasets on this frontier are optimal, meaning that there exists no matching solution with a lower imbalance for a given sample size or a higher sample size for a fixed imbalance. Imbalance was measured by average Mahalanobis imbalance (AMI) metric, that is the Mahalanobis distance between each unit in the treatment group and the closest unit in the control group averaged over all units.



Ch.3 Figure 9. Standardized mean difference along the Matching Frontier for the matching based on seven confounders. Standardized mean difference was calculated dividing mean differences by standard deviation of the treated group.



Ch.3 Figure 10. Standardized mean difference along the Matching Frontier for the matching based on five confounders; in addition, standardized mean differences for the two covariates “Agricultural zone” and “Agricultural education”.



3.4 Discussion and Conclusion

This study is the first application of the Matching Frontier method in the field of livestock science. The method proved to be a good complement to previous matching approaches in observational studies. It has especially added value in situations where the groups to be compared differ considerably in their characteristics. In such cases, matching alone is often insufficient to achieve sufficient balance and overlap, but additional pruning of observations is necessary.

The Matching Frontier method, developed by King et al. (2017), has several advantages over manual pruning approaches. First, all datasets on the Matching Frontier are optimal regarding balance and sample size. Researchers can thus focus on the trade-off between these two. Second, by visualizing the covariate mean difference along the Matching Frontier, the exact dataset can be selected where all covariates are below the desired cut-off value. It would be a great challenge to match exactly this dataset with manual approaches. Third, by calculating and visualizing model dependence, researchers can see how much is actually gained regarding reduced model dependence by pruning observations. The fourth point is shown in the comparison between the matching solution based on five confounders and the matching solution based on seven confounders. Pruning of observations can also improve the balance in covariates that were not included in the matching. Thus, a matching based on just a subset of confounders can induce a better result regarding overall balance than a matching based on all confounders. Whether this is actually the case depends strongly on the structure of the dataset and the confounders used. However, checking this is facilitated by the Matching Frontier method.

The Matching Frontier method could have been useful in Odermatt et al. (2018), for example. As in this study, farms included in the free stall program were compared with non-participants, and balance was increased using a matching approach. Standardized mean differences of the matching solution are not explicitly given. However, from the given absolute means for the treatment and control groups, it is possible to conclude that the standardized mean differences in some covariates were above the cut-off value of 0.1. Pruning of single observations would probably have allowed a higher balance without sacrificing a considerable sample size.

The adequacy of the indicators used for the areas studied in the present study has been demonstrated several times. The four variables, “Mastitis”, “Culled cows”, “HSCC”, and “High cell”, have proven to be useful udder health indicators in various studies (Alvåsen et al., 2012; Bartlett et al., 2001; Bradley et al., 2007; Gordon et al., 2013; Madouasse et al., 2010; Miller et al., 2008; Olde Riekerink et al., 2008; O’Reilly et al., 2006; Pantoja et al., 2009; Peeler et al., 2002; Schukken et al., 2003; Valde et al., 2005, 1997; van den Borne et al., 2010) Veterinary costs were included in the study because they can affect the profitability of dairy farming, which can be an important consideration for farmers (Odermatt et al., 2018). Farmers were additionally asked how much of the total veterinary costs were spent on insemination. This is because, depending on the farm, insemination was performed by the veterinarian, breeding association, or farm manager. Therefore, to make veterinary costs comparable between farms, they had to be adjusted for artificial insemination costs. Antibiotic treatment incidence has proven to be a useful indicator of the amount of antibiotic use in three studies in Switzerland (Menéndez González et al., 2010; Schaeren, 2006; Spycher et al., 2002).

The present analysis, based on the Matching Frontier, suggests that the free stall program with increased lying comfort has a positive effect on udder health, veterinary costs, and antibiotic usage. Thus, free stall housing is not only more accepted by non-producers, but also seems to be associated with benefits for farmers and public health.

Incidence rates for mastitis, with a median of 11.65 cases per 100 cow-years (mean 12.99), were in the range of another Swiss questionnaire study, which reported a median of 11.6 cases per 100 cow-years (mean 14.7) (Gordon et al., 2013). Studies in Denmark (Bartlett et al., 2001), Norway (Valde et al., 2005), England and Wales (Bradley et al., 2007), Canada (Olde Riekerink et al., 2008), and the Netherlands (van den Borne et al., 2010) reported higher values. However, it is important to distinguish that study farmers in countries other than Switzerland were asked to report the number of quarters affected rather than the number of cows affected (Gordon et al., 2013). The positive effect of the free stall program on the incidence of mastitis is in accordance with results found in previous studies (Hultgren, 2002; Olde Riekerink et al., 2008; Valde et al., 1997). Mastitis incidences in free stalls were, on average, lower by 25%. The size of the effect is in the range of other studies, where incidences in free stalls were lower by 25% (Valde et al., 1997) and 28% (Olde Riekerink et al., 2008). The average number of cows in the matched treatment group was 27 cows. A treated farm of this size would have one mastitis case less per year compared to a tie stall farm of the same size. Costs of mastitis are complex to estimate, and no standardized approach exists (Halasa et al., 2007; Heikkilä et al., 2012). Heikkilä et al. (2012) estimated the average costs of a clinical mastitis case based on Finnish dairy cows to 485 €, with a range from 209 € to 1006 €. On Canadian farms, the median cost for a clinical mastitis case was 744 Canadian dollars (CAD) (range: 50 CAD to 5.349 CAD) (Aghamohammadi et al., 2018). For Switzerland, costs of 209 CHF per cow-year at risk for clinical and subclinical mastitis were estimated (Heiniger et al., 2014). For the latter, no estimates per mastitis case were reported.

Although the exact costs of mastitis are difficult to estimate, the difference found in one mastitis case per year for an average sized farm seems to be relevant for the profitability of the farm.

The mean of 4.31 culled cows per 100 cow-years (median 2.82) was lower than reported in a Norwegian study (mean of 7.6, median of six culled cows per 100 cow-years) (Valde et al., 2005). A study showed that premature culling increased the already high costs of mastitis by 28% (Heikkilä et al., 2012). The positive effect of the free stall program (−2.80 cows per 100 cow-years) thus suggests that farms can save costs caused by premature culling by keeping cows in free stalls. The effect cannot be compared to other studies, as it has not been investigated before.

No significant difference between the two groups could be found for average herd somatic cell count and the number of cows with cell counts level above 150.000. This is in accordance with two studies from Norway and Sweden (Hultgren, 2002; Valde et al., 1997). However, two studies in Switzerland found higher HSCC levels in free stalls (Bielfeldt et al., 2004; Gordon et al., 2013), whereas results in Dufour et al. (2011) (Dufour et al., 2011) indicated the opposite.

The result that farms with free stalls had significantly low veterinary costs follows a Swiss study (Odermatt et al., 2018). The effect in this study was higher, with a value of −42.44 CHF per cow-year compared to −19.32 CHF. This effect could have a significant impact on the profitability of milk production, which could be an argument for farmers switching to free stall housing. However, Odermatt et al. (2018) specified the limitations of veterinary costs as an indicator of the level of animal health. Low costs could be related to healthy animals, but also to the non-treatment of animals that need veterinary care.

Incidences of antibiotic treatments with a mean of 55.97 total intramammary treatments per 100 cow-years (20.09 treatments per 100 cow-years due to mastitis and 36.04 treatments per 100 cow-years for dry-cow therapy) were lower than reported in previous studies in Switzerland. In Menéndez González et al. (2010), the mean incidence of total intramammary antibiotic treatments was 76 per 100 cow-years (37 for mastitis and 39 for dry-cow therapy). Schaeren and Alp (2006) reported a mean incidence of 61 treatments per 100 cow-years (25 due to mastitis and 36 for dry-cow therapy). In Spycher (2002), the mean incidence of treatments due to mastitis was 26 per 100 cow-years. The difference from previous studies is mainly in the treatments due to mastitis, whereas treatments for dry-cow therapy are in a similar range. The quantity of antibiotics sold for veterinary medicine has decreased in Switzerland in recent years (FOPH, 2020). However, it is unclear whether this can explain the difference from previous studies, as the amount of antibiotics sold for both mastitis and dry-cow therapy has decreased. The trend in this study was only evident in mastitis treatments.

The difference in antibiotic treatments found between farms with free stalls and farms with tie stalls is significant. Free stall farms thus had a 23% lower incidence of total intramammary antibiotic treatments, a 32% lower incidence of antibiotic treatments for mastitis therapy, and a 21% lower incidence of treatments for dry-cow therapy. The treatment effect of −7.83 per 100 cow-years in the incidence of antibiotic treatments for mastitis therapy is slightly lower than in Spycher et al. (2002), who reported 9.3 fewer treatments per 100 cow-years. To the best of the authors' knowledge, no other study has examined the effect of free stalling on antibiotic usage, to which the effect could be compared to. Fewer treatments with antibiotics in free stalls can induce lower costs for farmers and can thus be associated with economic benefits. However, free stalls also seem beneficial to the public, as the reduced use of antibiotics can have a positive impact on public health. This may further increase the acceptance of free stalls. However, it is important to note that the link between the incidence of intramammary treatments and public health is complex. First, intramammary antibiotic treatments represent only a part of antibiotic treatments in dairy cattle. With 75% (Schaeren, 2006) and 71% (Menéndez González et al., 2010), respectively, they took up a considerable portion of the treatments, but other treatments were not considered in this study. Additionally, it is difficult to draw conclusions from the number of treatments regarding the quantities, dosages, and duration of therapy used. Also, no active substances used were collected, which means that no statement can be made about possible critical antibiotics used, which could be important for human medicine. Also, the link between exposure to antibiotics and the emergence of resistance is complex and still under investigation. However, some studies have suggested that the higher the antibiotic use, the more likely it is that resistance will occur (Helke et al., 2017; Oliver et al., 2020, 2011; Omwenga et al., 2021; Pol and Ruegg, 2007).

Six of the eight effects studied are significant and indicate that free stall farming is associated with better udder health and, thus, cost benefits for the farmer. Notably, the effects found are not additive. The eight independent variables correlate with each other because they all represent some aspect of udder health. For example, the costs saved by fewer cases of mastitis are already reflected in veterinary costs, and the same is true for fewer treatments.

Through the combination of free-walking and increased lying comfort in the voluntary program, specific requirements responsible for the treatment effects cannot be determined from the results of this study. When applying the results to other countries, the prevailing specific housing conditions must therefore be considered.

This study has some limitations. Participation in the survey was voluntary. Therefore, a selection bias must be assumed. It is possible that more motivated farmers participated. Also, all data was self-reported. It cannot be verified whether all farmers correctly recorded treatments. Studies have shown that poorly kept treatment journals can be a problem, leading to an underestimation of the number of treatments (Carson et al., 2008; Menéndez González et al., 2010). A further limitation of the study is that omitted variable bias cannot be completely ruled out. Central differences between the two groups were controlled for by five and seven confounders, respectively. It was also shown that matching and pruning of observations reduced the balance in variables that were not included in the matching. However, it is possible that unobservable effects that could not be controlled for influence both the outcome and treatment variables. Therefore, further studies on this topic should include more covariates to address potential omitted-variable bias.

Overall, although no final conclusion can be drawn, the study results suggest that free stall housing, in combination with increased lying comfort, is associated with better udder health, lower veterinary costs, and public health benefits. Promoting free stall housing with public funding, as in Switzerland, therefore seems sensible. The Matching Frontier method applied in the study may facilitate future observational studies in which the treatment and control groups differ considerably in their characteristics.

References

Abadie, A., Imbens, G.W., 2006. Large Sample Properties of Matching Estimators for Average Treatment Effects. Econometrica 74, 235–267. https://doi.org/10.1111/j.1468-0262.2006.00655.x

Aghamohammadi, M., Haine, D., Kelton, D.F., Barkema, H.W., Hogeveen, H., Keefe, G.P., Dufour, S., 2018. Herd-Level Mastitis-Associated Costs on Canadian Dairy Farms. Front. Vet. Sci. 5. https://doi.org/10.3389/fvets.2018.00100

Alvåsen, K., Jansson Mörk, M., Hallén Sandgren, C., Thomsen, P.T., Emanuelson, U., 2012. Herd-level risk factors associated with cow mortality in Swedish dairy herds. J. Dairy Sci. 95, 4352–4362. https://doi.org/10.3168/jds.2011-5085

Athey, S., Imbens, G., 2015. A Measure of Robustness to Misspecification. Am. Econ. Rev. 105, 476–480. https://doi.org/10.1257/aer.p20151020

Austin, P.C., 2013. The performance of different propensity score methods for estimating marginal hazard ratios. Stat. Med. 32, 2837–2849. https://doi.org/10.1002/sim.5705

Austin, P.C., 2009. Type I Error Rates, Coverage of Confidence Intervals, and Variance Estimation in Propensity-Score Matched Analyses. Int. J. Biostat. 5. https://doi.org/10.2202/1557-4679.1146

Austin, P.C., Small, D.S., 2014. The use of bootstrapping when using propensity-score matching without replacement: a simulation study. Stat. Med. 33, 4306–4319. https://doi.org/10.1002/sim.6276

Bartlett, P.C., Agger, J.F., Houe, H., Lawson, L.G., 2001. Incidence of clinical mastitis in Danish dairy cattle and screening for non-reporting in a passively collected national surveillance system. Prev. Vet. Med. 48, 73–83. https://doi.org/10.1016/S0167-5877(00)00192-6

Bielfeldt, J.C., Badertscher, R., Tölle, K.-H., Krieter, J., 2004. Factors influencing somatic cell score in Swiss dairy production systems. Schweiz. Arch. Für Tierheilkd. 146, 555–560. https://doi.org/10.1024/0036-7281.146.12.555

Bradley, A.J., Leach, K.A., Breen, J.E., Green, L.E., Green, M.J., 2007. Survey of the incidence and aetiology of mastitis on dairy farms in England and Wales. Vet. Rec. 160, 253–258. https://doi.org/10.1136/vr.160.8.253

Carson, C.A., Reid-Smith, R., Irwin, R.J., Martin, W.S., McEwen, S.A., 2008. Antimicrobial use on 24 beef farms in Ontario. Can. J. Vet. Res. 72, 109–118.

Dufour, S., Fréchette, A., Barkema, H.W., Mussell, A., Scholl, D.T., 2011. Invited review: effect of udder health management practices on herd somatic cell count. J. Dairy Sci. 94, 563–579. https://doi.org/10.3168/jds.2010-3715

European Commission. Directorate General for Health and Food Safety., TNS Political & Social., 2015. Attitudes of Europeans towards animal welfare: report. Publications Office, LU.

FOAG, 2020. Agricultural Report 2020. Federal Office for Agriculture, Bern.

FOPH, 2020. Swiss Antibiotic Resistance Report 2020. Usage of Antibiotics and Occurrence of Antibiotic Resistance in Switzerland. Federal Office of

Public Health and Federal Food Safety and Veterinary Office., FOPH publication number: 2020-OEG-6.

Gayat, E., Resche-Rigon, M., Mary, J.-Y., Porcher, R., 2012. Propensity score applied to survival data analysis through proportional hazards models: a Monte Carlo study. Pharm. Stat. 11, 222–229. https://doi.org/10.1002/pst.537

Gelman, A., Hill, J., Vehtari, A., 2020. Regression and Other Stories, 1st ed. Cambridge University Press. https://doi.org/10.1017/9781139161879

Gordon, P.F., van den Borne, B.H., Reist, M., Kohler, S., Doherr, M.G., 2013. Questionnaire-based study to assess the association between management practices and mastitis within tie-stall and free-stall dairy housing systems in Switzerland. BMC Vet. Res. 9, 200. https://doi.org/10.1186/1746-6148-9-200

Greifer, N., 2021a. MatchIt: Getting Started [WWW Document]. URL https://cran.r-project.org/web/packages/MatchIt/vignettes/MatchIt.html (accessed 6.20.21).

Greifer, N., 2021b. Estimating Effects After Matching [WWW Document]. URL https://cran.r-project.org/web/packages/MatchIt/vignettes/MatchIt.html (accessed 6.20.21).

Halasa, T., Huijps, K., Østerås, O., Hogeveen, H., 2007. Economic effects of bovine mastitis and mastitis management: A review. Vet. Q. 29, 18–31. https://doi.org/10.1080/01652176.2007.9695224

Heikkilä, A.-M., Nousiainen, J.I., Pyörälä, S., 2012. Costs of clinical mastitis with special reference to premature culling. J. Dairy Sci. 95, 139–150. https://doi.org/10.3168/jds.2011-4321

Heiniger, D., van den Borne, B.H.P., Lechner, I., Tschopp, A., Strabel, D., Steiner, A., Meier, H., 2014. Kosten-Nutzen-Analyse einer Intervention zur Verbesserung der Eutergesundheit in Schweizer Milchviehbetrieben. Schweiz. Arch. Für Tierheilkd. 156, 473–481. https://doi.org/10.1024/0036-7281/a000634

Helke, K.L., McCrackin, M.A., Galloway, A.M., Poole, A.Z., Salgado, C.D., Marriott, B.P., 2017. Effects of antimicrobial use in agricultural animals on drug-resistant foodborne salmonellosis in humans: A systematic literature review. Crit. Rev. Food Sci. Nutr. 57, 472–488. https://doi.org/10.1080/10408398.2016.1230088

Hill, J., Reiter, J.P., 2006. Interval estimation for treatment effects using propensity score matching. Stat. Med. 25, 2230–2256. https://doi.org/10.1002/sim.2277

Ho, D.E., Imai, K., King, G., Stuart, E.A., 2007. Matching as Nonparametric Preprocessing for Reducing Model Dependence in Parametric Causal Inference. Polit. Anal. 15, 199–236. https://doi.org/10.1093/pan/mpl013

Hultgren, J., 2002. Foot/leg and udder health in relation to housing changes in Swedish dairy herds. Prev. Vet. Med. 53, 167–189. https://doi.org/10.1016/S0167-5877(01)00279-3

Imbens, G.W., Wooldridge, J.M., 2009. Recent Developments in the Econometrics of Program Evaluation. J. Econ. Lit. 47, 5–86. https://doi.org/10.1257/jel.47.1.5

King, G., Lucas, C., Nielsen, R., 2015. MatchingFrontier: R Package for Computing the Matching Frontier.

King, G., Lucas, C., Nielsen, R.A., 2017. The Balance-Sample Size Frontier in Matching Methods for Causal Inference. Am. J. Polit. Sci. 61, 473–489. https://doi.org/10.1111/ajps.12272

Kreif, N., Gruber, S., Radice, R., Grieve, R., Sekhon, J.S., 2016. Evaluating treatment effectiveness under model misspecification: A comparison of targeted maximum likelihood estimation with bias-corrected matching. Stat. Methods Med. Res. 25, 2315–2336. https://doi.org/10.1177/0962280214521341

Ly, L.H., Ryan, E.B., Weary, D.M., 2021. Public attitudes toward dairy farm practices and technology related to milk production. PLoS ONE 16, e0250850. https://doi.org/10.1371/journal.pone.0250850

Madouasse, A., Huxley, J.N., Browne, W.J., Bradley, A.J., Green, M.J., 2010. Somatic cell count dynamics in a large sample of dairy herds in England and Wales. Prev. Vet. Med. 96, 56–64. https://doi.org/10.1016/j.prevetmed.2010.05.005

Menéndez González, S., Steiner, A., Gassner, B., Regula, G., 2010. Antimicrobial use in Swiss dairy farms: Quantification and evaluation of data quality. Prev. Vet. Med. 95, 50–63. https://doi.org/10.1016/j.prevetmed.2010.03.004

Miller, R.H., Kuhn, M.T., Norman, H.D., Wright, J.R., 2008. Death Losses for Lactating Cows in Herds Enrolled in Dairy Herd Improvement Test Plans. J. Dairy Sci. 91, 3710–3715. https://doi.org/10.3168/jds.2007-0943

Odermatt, B., Keil, N., Lips, M., 2018. Animal Welfare Payments and Veterinary and Insemination Costs for Dairy Cows. Agriculture 9, 3. https://doi.org/10.3390/agriculture9010003

Olde Riekerink, R.G.M., Barkema, H.W., Kelton, D.F., Scholl, D.T., 2008. Incidence Rate of Clinical Mastitis on Canadian Dairy Farms. J. Dairy Sci. 91, 1366–1377. https://doi.org/10.3168/jds.2007-0757

Oliver, J.P., Gooch, C.A., Lansing, S., Schueler, J., Hurst, J.J., Sassoubre, L., Crossette, E.M., Aga, D.S., 2020. Invited review: Fate of antibiotic residues, antibiotic-resistant bacteria, and antibiotic resistance genes in US dairy manure management systems. J. Dairy Sci. 103, 1051–1071. https://doi.org/10.3168/jds.2019-16778

Oliver, S.P., Murinda, S.E., Jayarao, Bhushan.M., 2011. Impact of Antibiotic Use in Adult Dairy Cows on Antimicrobial Resistance of Veterinary and Human Pathogens: A Comprehensive Review. Foodborne Pathog. Dis. 8, 337–355. https://doi.org/10.1089/fpd.2010.0730

Omwenga, I., Aboge, G.O., Mitema, E.S., Obiero, G., Ngaywa, C., Ngwili, N., Wamwere, G., Wainaina, M., Bett, B., 2021. Antimicrobial Usage and Detection of Multidrug-Resistant Staphylococcus aureus, Including Methicillin-Resistant Strains in Raw Milk of Livestock from Northern Kenya. Microb. Drug Resist. 27, 843–854. https://doi.org/10.1089/mdr.2020.0252

O'Reilly, K.M., Green, M.J., Peeler, E.J., Fitzpatrick, J.L., Green, L.E., 2006. Investigation of risk factors for clinical mastitis in British dairy herds with bulk milk somatic cell counts less than 150,000 cells/ml. Vet. Rec. 158, 649–653. https://doi.org/10.1136/vr.158.19.649

Pantoja, J.C.F., Hulland, C., Ruegg, P.L., 2009. Dynamics of somatic cell counts and intramammary infections across the dry period. Prev. Vet. Med. 90, 43–54. https://doi.org/10.1016/j.prevetmed.2009.03.012

Peeler, E.J., Green, M.J., Fitzpatrick, J.L., Green, L.E., 2002. Study of clinical mastitis in British dairy herds with bulk milk somatic cell counts less than 150,000 cells/ml. Vet. Rec. 151, 170–176. https://doi.org/10.1136/vr.151.6.170

Pol, M., Ruegg, P.L., 2007. Relationship Between Antimicrobial Drug Usage and Antimicrobial Susceptibility of Gram-Positive Mastitis Pathogens. J. Dairy Sci. 90, 262–273. https://doi.org/10.3168/jds.S0022-0302(07)72627-9

Regula, G., Danuser, J., Spycher, B., Wechsler, B., 2004. Health and welfare of dairy cows in different husbandry systems in Switzerland. Prev. Vet. Med. 66, 247–264. https://doi.org/10.1016/j.prevetmed.2004.09.004

Robbins, J.A., Roberts, C., Weary, D.M., Franks, B., Keyserlingk, M.A.G. von, 2019. Factors influencing public support for dairy tie stall housing in the U.S. PLOS ONE 14, e0216544. https://doi.org/10.1371/journal.pone.0216544

Rubin, D.B., 1973. The Use of Matched Sampling and Regression Adjustment to Remove Bias in Observational Studies. Biometrics 29, 185–203. https://doi.org/10.2307/2529685

Rubin, D.B., Thomas, N., 2000. Combining Propensity Score Matching with Additional Adjustments for Prognostic Covariates. J. Am. Stat. Assoc. 95, 573–585. https://doi.org/10.2307/2669400

Schaeren, W., 2006. Nutztiere Antibiotikaverbrauch 2003 und 2004 in der Milchproduktion. Agrar. Schweiz 13, 234–239.

Schukken, Y.H., Wilson, D.J., Welcome, F., Garrison-Tikofsky, L., Gonzalez, R.N., 2003. Monitoring udder health and milk quality using somatic cell counts. Vet. Res. 34, 579–596. https://doi.org/10.1051/vetres:2003028

Sizemore, S., Alkurdi, R., 2019. Matching Methods for Causal Inference: A Machine Learning Update [WWW Document]. URL https://humboldt-wi.github.io/blog/research/applied_predictive_modeling_19/matching_methods// (accessed 6.20.21).

Spycher, B., Regula, G., Wechsler, B., Danuser, J., 2002. Gesundheit und Wohlergehen von Milchkühen in verschiedenen Haltungsprogrammen. Schweiz. Arch. Für Tierheilkd. 144, 519–530. https://doi.org/10.1024/0036-7281.144.10.519

Stuart, E.A., 2010. Matching Methods for Causal Inference: A Review and a Look Forward. Stat. Sci. 25, 1–21. https://doi.org/10.1214/09-STS313

Swiss National Science Foundation, 2021. Providing the right incentives - Project description [WWW Document]. Antimicrob. Resist. - Natl. Res. Programme 72. URL http://www.nfp72.ch/en/projects/module-3-optimised-use-of-antibiotics/providing-the-right-incentives (accessed 6.20.21).

Valde, J.P., Hird, D.W., Thurmond, M.C., Østerås, O., 1997. Comparison of Ketosis, Clinical Mastitis, Somatic Cell Count, and Reproductive Performance between Free Stall and Tie Stall Barns in Norwegian Dairy Herds with Automatic Feeding. Acta Vet. Scand. 38, 181–192. https://doi.org/10.1186/BF03548498

Valde, J.P., Østerås, O., Simensen, E., 2005. Description of Herd Level Criteria for Good and Poor Udder Health in Norwegian Dairy Cows. J. Dairy Sci. 88, 86–92. https://doi.org/10.3168/jds.S0022-0302(05)72665-5

van den Borne, B.H.P., van Schaik, G., Lam, T.J.G.M., Nielen, M., 2010. Variation in herd level mastitis indicators between primi- and multiparae in Dutch dairy herds. Prev. Vet. Med. 96, 49–55. https://doi.org/10.1016/j.prevetmed.2010.05.010

Waldrop, M.E., Roosen, J., 2021. Consumer acceptance and willingness to pay for cow housing systems in eight European countries. Q Open 1. https://doi.org/10.1093/qopen/qoab001

Wan, F., 2019. Matched or unmatched analyses with propensity-score–matched data? Stat. Med. 38, 289–300. https://doi.org/10.1002/sim.7976

Wolf, C.A., Tonsor, G.T., McKendree, M.G.S., Thomson, D.U., Swanson, J.C., 2016. Public and farmer perceptions of dairy cattle welfare in the United States. J. Dairy Sci. 99, 5892–5903. https://doi.org/10.3168/jds.2015-10619

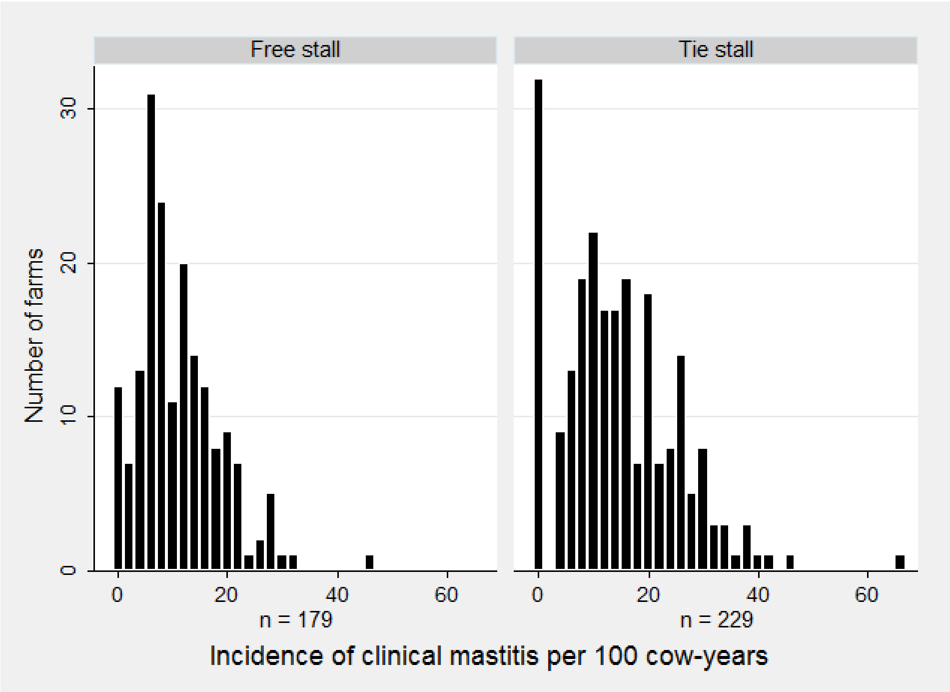
Zeileis, A., 2004. Econometric Computing with HC and HAC Covariance Matrix Estimators. J. Stat. Softw. 11, 1–17. https://doi.org/10.18637/jss.v011.i10

Zeileis, A., Hothorn, T., 2002. Diagnostic Checking in Regression Relationships. R News 2, 7–10.

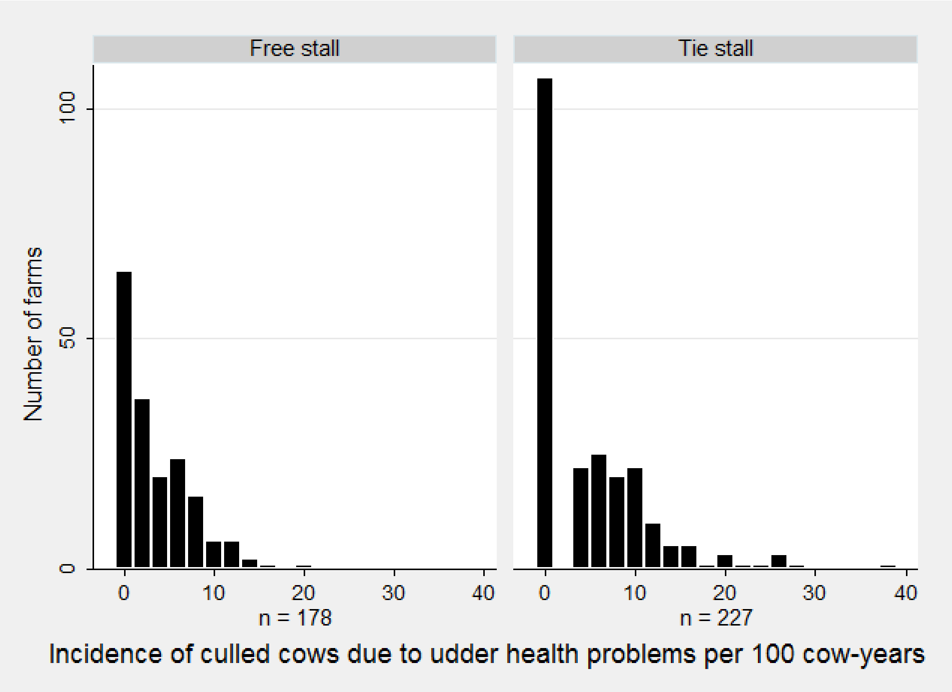
Appendix

Appendix A

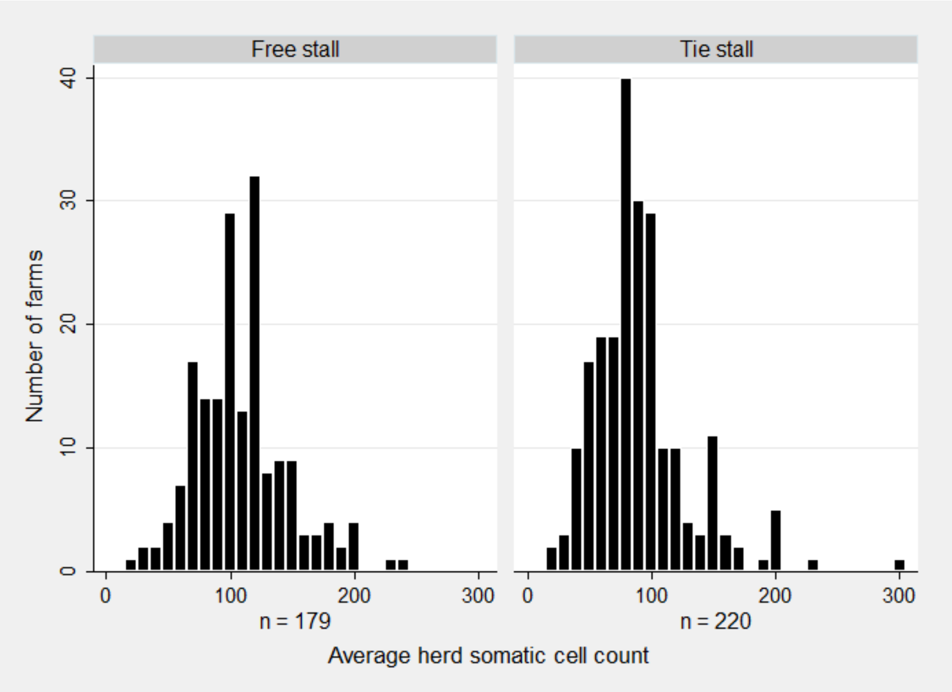
Ch.3 Appendix A Figure 1. Histogram of incidence of clinical mastitis



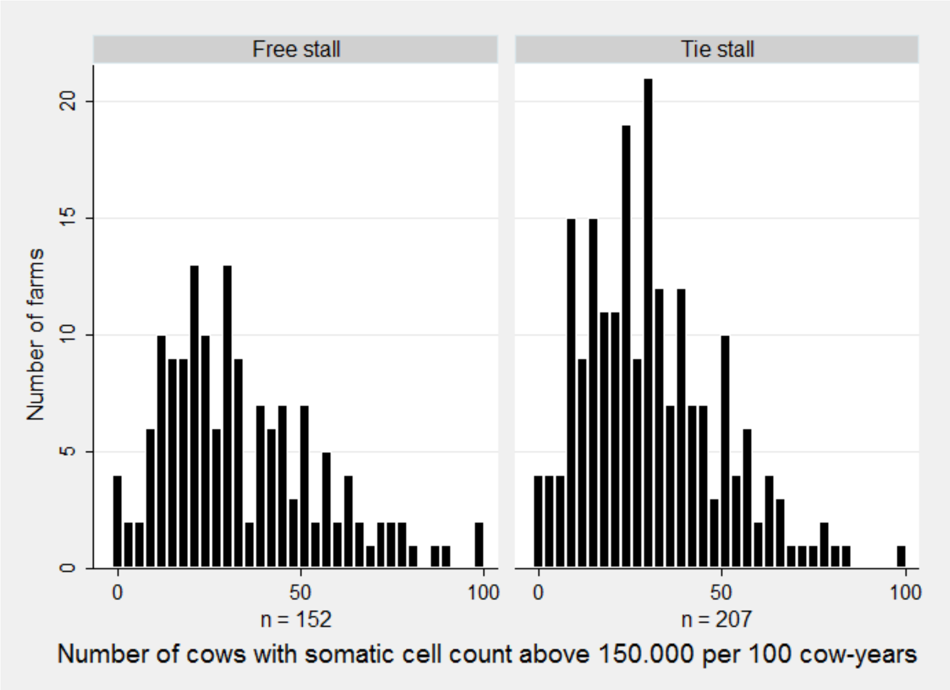
Ch.3 Appendix A Figure 2. Histogram of incidence of culled cows due to udder health problems



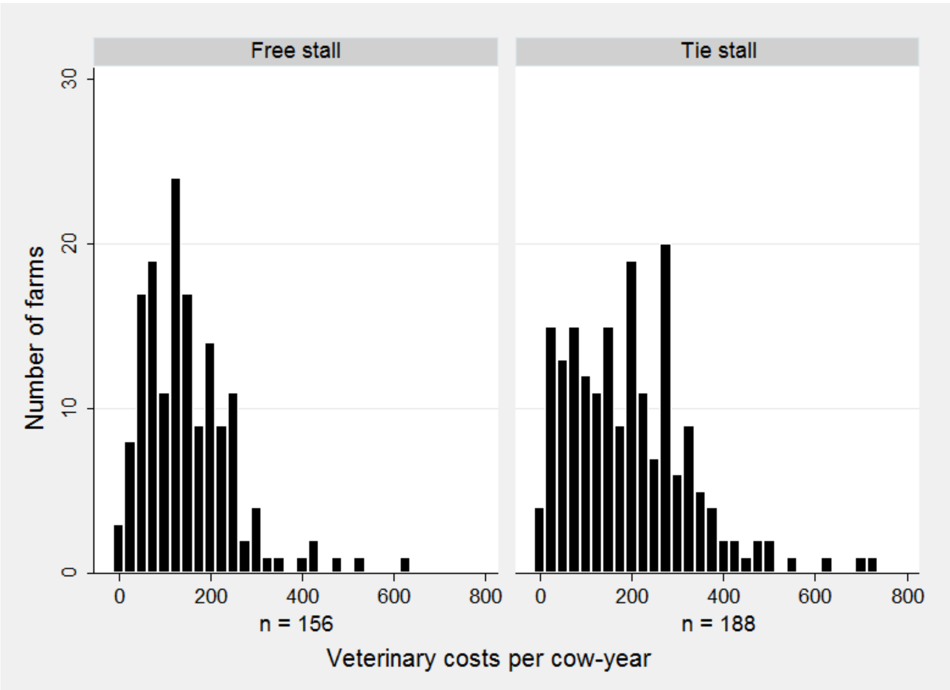
Ch.3 Appendix A Figure 3. Histogram of average herd somatic cell count



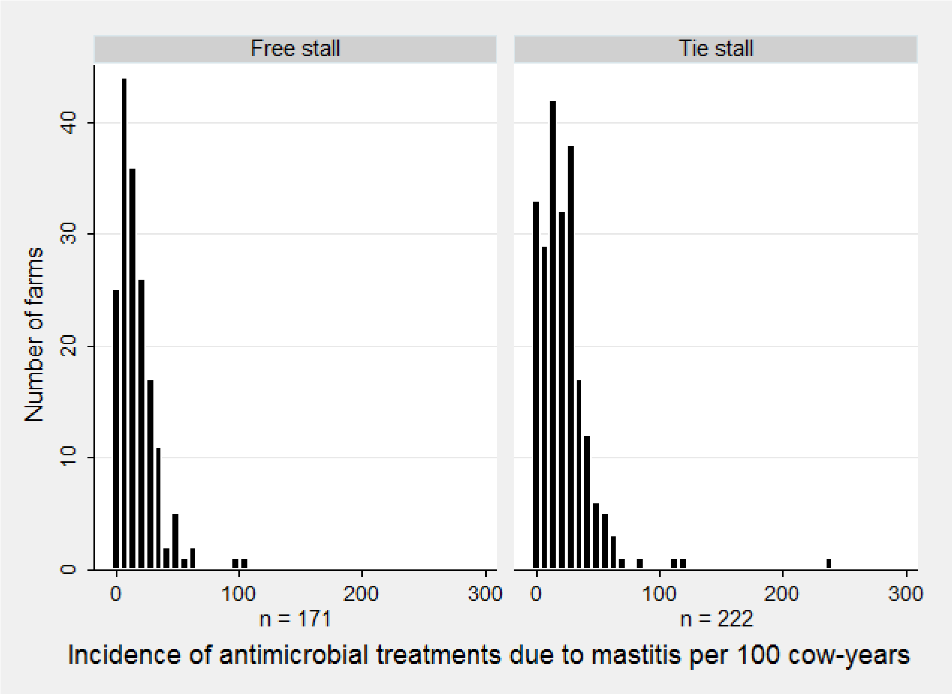
Ch.3 Appendix A Figure 4 Histogram of number of cows with somatic cell count above 150.000



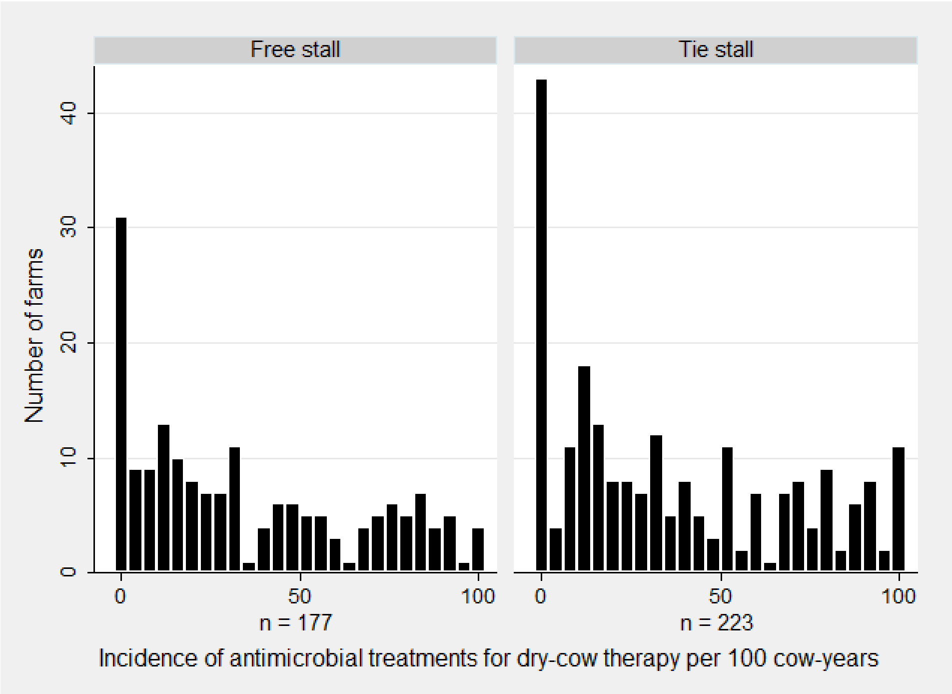
Ch.3 Appendix A Figure 5. Histogram of veterinary costs



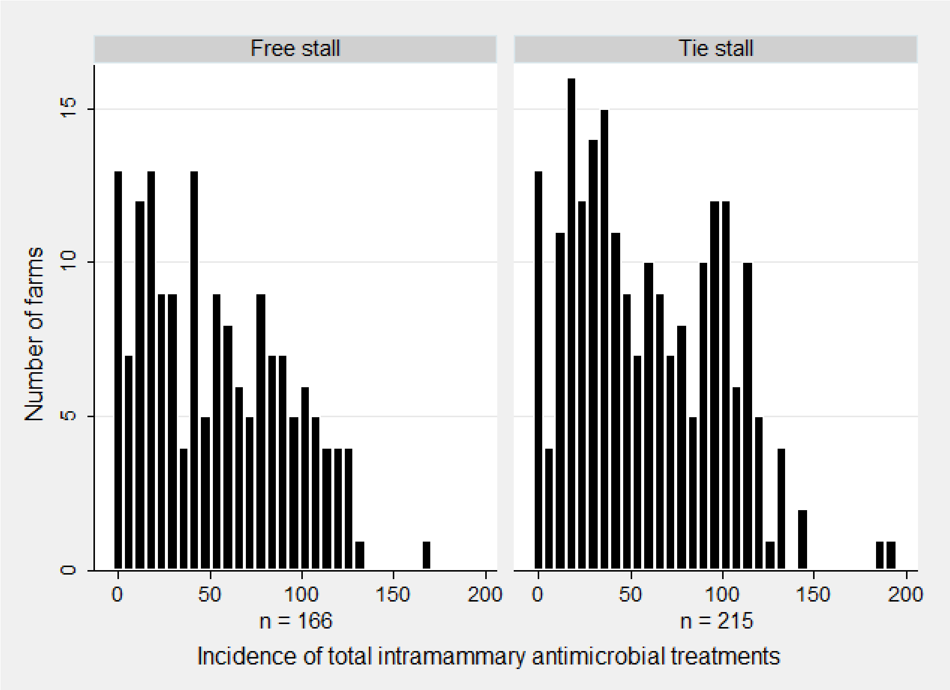
Ch.3 Appendix A Figure 6. Histogram of antibiotic treatments for mastitis therapy



Ch.3 Appendix A Figure 7. Histogram of antibiotic treatments for dry-cow therapy



Ch.3 Appendix A Figure 8. Histogram of total intramammary antibiotic treatments



Appendix B

Ch.3 Appendix B. Summary statistics of continues covariate "Number of cows" from treatment group ("Free stall") and control group ("Tie stall") for 7 different outcome variable models. Numbers for the model where "Incidence of clinical mastitis" was the outcome variable can be found in Table 3.

Outcome variable model	Variable	Treatment group	N	Mean	SD	Median	Min	Max
Culled cows[a]	Number of cows	Free stall	178	37.03	18.67	35	4	92
		Tie stall	227	18.85	7.94	19	3	45
HSCC[b]	Number of cows	Free stall	179	38.45	18.78	35	5	92
		Tie stall	220	19.12	7.91	19	3	45
High cell[c]	Number of	Free stall	152	37.85	19.01	35	4	92

	cows	Tie stall	207	18.58	7.85	18	3	45
Veterinary costs[d]	Number of cows	Free stall	156	38.92	18.81	36	6	92
		Tie stall	188	18.82	8.20	18	4	45
Antibiotic mastitis[e]	Number of cows	Free stall	171	37.19	18.89	35	4	92
		Tie stall	222	18.36	7.87	18	3	45
Antibiotic dry-cow[f]	Number of cows	Free stall	177	38.16	19.39	35	4	92
		Tie stall	223	18.65	7.94	18	3	45
Antibiotic total[g]	Number of	Free stall	166	37.61	18.96	35	4	92

cows	Tie stall	215	18.41	7.89	18	3	45

[a] Incidence of culled cows due to udder health problems in 2018

[b] Average Herd somatic cell count throughout 2018

[c] Number of cows with somatic cell count above 150.000 at least once in 2018

[d] Cumulative veterinary costs for dairy cows throughout 2018

[e] Incidence of antibiotic treatments for mastitis therapy in 2018

[f] Incidence of antibiotic treatments for dry-cow therapy in 2018

[g] incidence of total intramammary antibiotic treatments in 2018

Appendix C

Ch.3 Appendix C. Summary statistics of dummy covariates from treatment group ("Free stall") and control group ("Tie stall") and result of t-test to check for statistical significance of mean difference for 7 different outcome variable models. Numbers for the model where "Incidence of clinical mastitis" was the outcome variable can be found in Table 4. The percentage reflects the proportion of organic farms and the proportion of participants in the outdoor and grassland program in the respective group.

Outcome variable model	Variable	Treatment group	Number of farms	%
Culled cows[c]	Organic farming	Free stall	178	19.1%
		Tie stall	227	13.7%
	Outdoor program[a]	Free stall	178	93.3%
		Tie stall	227	84.1%
	Grassland program[b]	Free stall	178	66.9%
		Tie stall	227	80.6%
HSCC[d]	Organic farming	Free stall	179	18.4%
		Tie stall	220	12.7%

	Outdoor program[a]	Free stall	179	93.3%
		Tie stall	220	85.9%
	Grassland program[b]	Free stall	179	66.5%
		Tie stall	220	81.4%
High cell[e]	Organic farming	Free stall	152	20.4%
		Tie stall	207	14.0%
	Outdoor program[a]	Free stall	152	94.7%
		Tie stall	207	86.0%
	Grassland program[b]	Free stall	152	67.8%
		Tie stall	207	82.1%
Veterinary costs[f]	Organic farming	Free stall	156	20.5%
		Tie stall	188	14.4%
	Outdoor program[a]	Free stall	156	93.6%
		Tie stall	188	85.6%
	Grassland	Free stall	156	65.4%

	program[b]	Tie stall	188	82.4%
Antibiotic mastitis[g]	Organic farming	Free stall	171	18.7%
		Tie stall	222	14.0%
	Outdoor program[a]	Free stall	171	93.6%
		Tie stall	222	83.3%
	Grassland program[b]	Free stall	171	66.1%
		Tie stall	222	81.1%
Antibiotic dry-cow[h]	Organic farming	Free stall	177	18.6%
		Tie stall	223	13.9%
	Outdoor program[a]	Free stall	177	93.8%
		Tie stall	223	83.4%
	Grassland program[b]	Free stall	177	66.7%
		Tie stall	223	81.6%
	Organic farming	Free stall	166	19.3%

Antibiotic total[i]		Tie stall	215	14.4%
	Outdoor program[a]	Free stall	179	94.0%
		Tie stall	229	83.3%
	Grassland program[b]	Free stall	179	66.9%
		Tie stall	229	81.4%

[a] Farms participating in the outdoor program must give their animals access to pasture or an outdoor run for a minimum period per year. For more detailed information please see Odermatt (2018)

[b] For participating farms in the plain zone and hilly zone, 75% of the feed ration must be roughage, while 85% must be roughage for farms in the mountain zone.

[c] Incidence of culled cows due to udder health problems in 2018

[d] Average Herd somatic cell count throughout 2018

[e] Number of cows with somatic cell count above 150.000 at least once in 2018

[f] Cumulative veterinary costs for dairy cows throughout 2018

[g] Incidence of antibiotic treatments for mastitis therapy in 2018

[h] Incidence of antibiotic treatments for dry-cow therapy in 2018

[i] incidence of total intramammary antibiotic treatments in 2018

Appendix D

Ch.3 Appendix D. Summary statistics of categorical covariates from treatment group ("Free stall") and control group ("Tie stall") for 7 different outcome variable models. Numbers for the model where "Incidence of clinical mastitis" was the outcome variable can be found in Table 5. To illustrate the differences between the groups, means based on categorical numbering of variables were calculated. A t-test was used to determine whether the difference between the means was statistically significant.

Outcome variable model	Variable	Treatment group	Number of farms	Mean[a]
Culled cows[e]	Milk production[b]	Free stall	178	4.02
		Tie stall	227	3.22
	Agricultural zone[c]	Free stall	178	2.01
		Tie stall	227	2.83
	Agricultural education[d]	Free stall	178	3.55
		Tie stall	227	4.11
HSCC[f]	Milk production[b]	Free stall	179	4.10
		Tie stall	220	3.28

	Agricultural zone[c]	Free stall	179	1.98
		Tie stall	220	2.81
	Agricultural education[d]	Free stall	179	4.11
		Tie stall	220	3.58
High cell[g]	Milk production[b]	Free stall	152	4.01
		Tie stall	207	3.27
	Agricultural zone[c]	Free stall	152	2.88
		Tie stall	207	2.10
	Agricultural education[d]	Free stall	152	4.11
		Tie stall	207	3.54
Veterinary costs[h]	Milk production[b]	Free stall	156	4.09
		Tie stall	188	3.28
	Agricultural zone[c]	Free stall	156	1.87
		Tie stall	188	2.86

	Agricultural education[d]	Free stall	156	4.29
		Tie stall	188	3.54
Antibiotic mastitis[i]	Milk production[b]	Free stall	171	4.03
		Tie stall	222	3.20
	Agricultural zone[c]	Free stall	171	2.00
		Tie stall	222	2.85
	Agricultural education[d]	Free stall	171	4.13
		Tie stall	222	3.51
Antibiotic dry-cow[j]	Milk production[b]	Free stall	177	4.04
		Tie stall	223	3.22
	Agricultural zone[c]	Free stall	177	1.97
		Tie stall	223	2.83
	Agricultural education[d]	Free stall	177	4.15
		Tie stall	223	3.53

Antibiotic total[k]	Milk production[b]	Free stall	166	3.19
		Tie stall	215	4.05
	Agricultural zone[c]	Free stall	166	1.99
		Tie stall	215	2.85
	Agricultural education[d]	Free stall	166	4.17
		Tie stall	215	3.52

[a] To calculate the mean, categorical numbering was used (1–7 for “Milk production” and” Agricultural education”, 1–6 for “Agricultural zone”). Please see Table 5 for more information on categorical numbering.

[b] Average level of yearly milk yield per cow

[c] Agricultural zone in which farm is placed (plain zone, hill zone, and mountain zone)

[d] Farmer’s agricultural education level. For further information on the Swiss educational system, please see https://www.edk.ch/en/education-system/diagram

[e] Incidence of culled cows due to udder health problems in 2018

[f] Average Herd somatic cell count throughout 2018

[g] Number of cows with somatic cell count above 150.000 at least once in 2018

[h] Cumulative veterinary costs for dairy cows throughout 2018

[i] Incidence of antibiotic treatments for mastitis therapy in 2018

[j] Incidence of antibiotic treatments for dry-cow therapy in 2018

[k] incidence of total intramammary antibiotic treatments in 2018

Appendix E

Ch.3 Appendix E. Results of the full regression models used to determine the treatment effect of the "Free stall program". The dependent variable was the corresponding outcome variable, independent variables were the treatment variable "Free stall program" and the five confounders "Number of cows", "Milk production", "Organic farming", "Outdoor program", and "Grassland program". Linear regression was performed in each case with the largest possible sample at which all confounders at the same time had a maximum standardized mean difference of 0.1. In addition, robust standard errors, t-value and p-value of statistical significance of all confounders were displayed.

Outcome variable model	Variable	Coefficient	Robust Standard Error	t-value	p-value
Mastitis[a]	Free stall program	-3.66	1.69	-2.16	0.031
n=308	Number of cows	0.02	0.11	0.15	0.884
	Milk production[i]	1.55	0.65	2.40	0.017
	Organic farming[j]	3.20	3.47	0.92	0.357

	Grassland program[k]	-2.70	3.80	-0.71	0.478
	Outdoor program[l]	3.35	2.80	1.19	0.233
	Intercept	7.08	3.40	2.08	0.038
Culled cows[b]	Free stall program	-1.61	0.66	-2.42	0.016
n=304	Number of cows	-0.05	0.04	-1.18	0.237
	Milk production[i]	0.75	0.32	2.34	0.020
	Organic farming[j]	0.51	1.05	0.48	0.630
	Grassland program[k]	1.73	0.87	2.00	0.047
	Outdoor program[l]	-2.41	2.60	-0.93	0.354
	Intercept	4.73	3.16	1.50	0.136

HSCC[c]	Free stall program	8.37	5.57	1.50	0.134
n=288	Number of cows	0.66	0.27	2.43	0.016
	Milk production[i]	-1.08	2.97	-0.36	0.716
	Organic farming[j]	10.92	7.11	1.53	0.126
	Grassland program[k]	12.88	11.51	1.12	0.264
	Outdoor program[l]	-19.02	7.62	-2.50	0.013
	Intercept	81.34	13.51	6.02	0.000
High cell[d]	Free stall program	-0.91	3.26	-0.28	0.782
n=241	Number of cows	0.38	0.23	1.66	0.098
	Milk production[i]	-0.43	1.76	-0.24	0.807

	Organic farming[j]	5.79	3.59	1.61	0.109
	Grassland program[k]	6.24	5.58	1.12	0.265
	Outdoor program[l]	3.93	5.48	0.72	0.474
	Intercept	12.92	9.52	1.36	0.176
Veterinary costs[e]	Free stall program	-42.44	17.94	-2.37	0.019
n=225	Number of cows	-1.81	1.07	-1.69	0.093
	Milk production[i]	34.38	11.81	2.91	0.004
	Organic farming[j]	13.77	25.97	0.53	0.596
	Grassland program[k]	18.13	42.75	0.42	0.672

	Outdoor program[l]	19.03	69.55	0.27	0.785
	Intercept	82.63	84.59	0.98	0.330
Antibiotic mastitis[f] n=290	Free stall program	-7.83	2.39	-3.28	0.001
	Number of cows	0.10	0.14	0.75	0.456
	Milk production[i]	3.70	1.39	2.65	0.008
	Organic farming[j]	-0.80	3.11	-0.26	0.797
	Grassland program[k]	2.60	4.60	0.57	0.572
	Outdoor program[l]	-7.85	10.81	-0.73	0.469
	Intercept	13.66	14.16	0.97	0.335

Antibiotic dry-cow[g]	Free stall program	-8.80	4.35	-2.02	0.044
n=283	Number of cows	0.46	0.29	1.55	0.121
	Milk production[i]	1.87	2.60	0.72	0.473
	Organic farming[j]	-25.25	4.27	-5.91	0.000
	Grassland program[k]	-12.76	6.31	-2.02	0.044
	Outdoor program[l]	14.65	9.70	1.51	0.132
	Intercept	24.12	13.74	1.76	0.080
Antibiotic total[h]	Free stall program	-15.88	4.99	-3.18	0.002
n=270	Number of cows	0.57	0.31	1.84	0.068

Milk production[i]	6.31	2.84	2.22	0.027
Organic farming[j]	-25.39	5.09	-4.99	0.000
Grassland program[k]	-8.42	9.18	-0.92	0.360
Outdoor program[l]	14.78	12.09	1.22	0.223
Intercept	25.10	17.35	1.45	0.149

[a] Incidence of clinical mastitis in 2018

[b] Incidence of culled cows due to udder health problems in 2018

[c] Average Herd somatic cell count throughout 2018

[d] Number of cows with somatic cell count above 150.000 at least once in 2018

[e] Cumulative veterinary costs for dairy cows throughout 2018

[f] Incidence of antibiotic treatments for mastitis therapy in 2018

[g] Incidence of antibiotic treatments for dry-cow therapy in 2018

[h] incidence of total intramammary antibiotic treatments in 2018

[i] Farms participating in the outdoor program must give their animals access to pasture or an outdoor run for a minimum period per year. For more detailed information please see Odermatt (2018)

[j] For participating farms in the plain zone and hilly zone, 75% of the feed ration must be roughage, while 85% must be roughage for farms in the mountain zone.

Chapter 4. Article 3. Assessing farmer willingness to participate in a subsidized veterinary herd health management program

Armin van Aken [a b]

[a] University of Geneva, Geneva School of Social Sciences, Boulevard du Pont d′ Arve 40, 1211 Geneva, Switzerland

[b] Agroscope, Research Division Competiveness and System Evaluation, Tänikon 1, CH-8356 Ettenhausen, Switzerland

Published in:

Preventive Veterinary Medicine

Volume 220, November 2023, 106031

https://doi.org/10.1016/j.prevetmed.2023.106031

Abstract

Zoonoses, such as COVID-19, can cause pandemics with many fatalities. Therefore, livestock keepers should attach great importance to livestock disease control. Veterinarians can support farmers in this task through a structured veterinary herd health management (VHHM) program. The dissemination of these programs remained low, and the Swiss policy makers planned to launch a subsidy program for VHHM.

To inform policy making ex-ante, a survey of 1600 Swiss dairy farmers was conducted to determine whether they are willing to participate and how much they are willing to pay. Contingent evaluation with a discrete choice format elicited willingness to pay (WTP). As a rather high share of farmers who would not participate was expected, a spike model was applied with a single-bounded discrete choice (SBDC) model.

Only 47% of the farmers had a positive WTP. Mean WTP in the SBDC was CHF 10.47 per cow and year and in the spike model CHF 57.96. Participation would increase with higher subsidy levels. If the government pays 20% of the costs and farmers pay CHF 96 per cow per year, 23.6% of farms would participate. If the subsidy increases to 80% (CHF 24 for farmers), 40.4% would participate. A logistic regression indicates younger and older farmers, those with lower veterinary costs, and those who consider VHHM relevant only for farms with problems are less likely to participate.

Keywords

Veterinary herd health management, Agricultural economy, Dairy, Switzerland, Contingent valuation, Survey, Animal health, Willingness to pay, Willingness to participate

4.1 Introduction

Zoonoses, such as COVID-19, can cause pandemics with many fatalities and enormous private and social costs (Padhan and Prabheesh, 2021). Therefore, livestock keepers bear a great responsibility, which is why they should attach great importance to livestock disease control. To support farmers, veterinarians can be integrated in the management of a farm, as they increasingly understand their role as animal health advisers on preventive measures and livestock disease control (Bard et al., 2017; Duval et al., 2016; Enticott et al., 2011; Ruston et al., 2016; Speksnijder et al., 2015; Speksnijder et al., 2017; Speksnijder and Wagenaar, 2018; Woodward et al., 2019). These veterinary herd health management (VHHM) services combine animal health, food safety, animal welfare, and public health with farm management and economics (LeBlanc et al., 2006; Noordhuizen and Metz, 200). VHHM programs are institutionalized in many countries in Europe, for example, the Netherlands (Derks et al., 2012), the UK (Wassell and Esslemont, 1992), Denmark (Kristensen and Enevoldsen, 2008), Sweden (Svensson et al., 2018), and Switzerland (Hool et al., 2020). However, the dissemination of VHHM remains low (Svensson et al., 2018).

Swiss policy makers planned to promote VHHM with financial support through a subsidized voluntary agricultural program (Bundesamt für Landwirtschaft, 2018). To inform policy making, the goal of the present study was to identify ex-ante farmers' willingness to participate in the planned program and their willingness to pay (WTP) for such services.

A range of studies, mainly conducted by veterinarians, have already dealt with VHHM to find out more about farmer perceptions of and attitudes toward VHHM.

Using qualitative approaches and surveys, these have sought to identify reasons for low participation rates. Farmers have mentioned high costs for VHHM as the primary reason for not participating (Derks et al., 2012; Gerber et al., 2020; Hool et al., 2020; Svensson et al., 2018), followed by low or unclear cost–benefit ratios (Svensson et al., 2018). These results show that economic aspects play a major role and give rise to the assumption that public intervention, for example, subsidies for the services offered, could have a positive effect on dissemination rates. However, these studies do not provide deeper economic insights and remain too superficial for the design of publicly supported programs.

The value added by the present study is its determination of the share of farmers that would participate in the aforementioned voluntary program and the average WTP of farmers for its services. Decision-makers can thus determine ex-ante how many farms would be reached and whether investment in the development of the intervention program would be worthwhile. In addition, the study provides numbers on how the subsidy level will influence participation rates.

4.2 Method

4.2.1 Measurement method: contingent valuation

To elicit farmer willingness to participate in and pay for a veterinary herd health program, the CV method was used. It has its origin in the valuation of environmental public goods (Carson and Hanemann, 2005). However, due to its flexibility, the CV method has since been used for many other questions. These include WTP for a tuberculosis cattle vaccine (Bennett and Balcombe, 2012), willingness to participate in best management practices through a proposed water quality trading program (Zhong et al., 2016), WTP for connection to a water supply or for electricity services (Komives et al., 2005), and WTP for crop insurance (Ellis and Ellis, 2017; Fahad and Jing, 2018; Mutaqin and Usami, 2019). CV has also proven to be a suitable method to support policy makers in setting subsidy levels (Whynes et al., 2005). In this sense, it is used in the present study.

4.2.2 Sampling and survey methods

The current study is based on an online and mail survey conducted in Switzerland between November 2019 and January 2020. A random sample of 1600 dairy farmers throughout Switzerland was asked to complete the questionnaire. Contact data for the farmers was provided by the Federal Office of Agriculture, which selected the sample from a database registering all farmers receiving direct payments. The selected farmers were sent a letter inviting them to take part in the online survey. Three weeks afterward, a reminder was sent to those who had not yet completed the online questionnaire. This reminder contained the paper-and-pencil questionnaire and a stamped, addressed return envelope.

4.2.3 Survey instrument: questionnaire

Great importance was attached to the development and testing of the questionnaire. First, in a focus group of 15 dairy farmers, basic perceptions and attitudes and previous experience with VHHM were examined to inform questionnaire development. As veterinarians would be responsible for implementation if the policy is introduced, qualitative interviews were conducted with practitioners and veterinarians working in science to investigate their points of view. The views of policy makers were also obtained through interviews.

Several farmers, veterinarians, and policy makers pretested the questionnaire to ensure understandability and credibility. In all, 100 farmers took part in a pilot study, which took place before the actual survey.

The questionnaire was structured into four main sections:

1. Basic farm and farmer information (agricultural zone, conventional vs. organic production, farm size, level of milk production, annual veterinary costs, age)
2. Explanation of the proposed policy
3. CV question with follow-up
4. Questions on attitudes and beliefs regarding VHHM

4.2.4 Explanation of the proposed policy

The results obtained from a CV study depend much upon the hypothetical setting proposed to the respondents (Carson and Hanemann, 2005). The debate in the literature about VHHM has led to a relatively uniform understanding in the academic world. However, this is only partly true for farmers and veterinarians in practice (Hool et al., 2020; Svensson et al., 2018). Beside the focus groups and interviews mentioned above, the understanding of VHHM and the formulations in the questionnaire were based closely on a position paper of the Swiss Veterinary Association (GST, 2020). It reflects, in a condensed form, the literature on VHHM (Derks et al., 2012; Derks et al., 2013; Duval et al., 2016, 2018; Gerber et al., 2020; Hall and Wapenaar, 2012; Hässig et al., 2010; Hool et al., 2020; Ifende et al., 2014; Kreausukon et al., 2004; Kristensen and Enevoldsen, 2008; Lievaart et al., 2008; Pendl et al., 2017; Speksnijder et al., 2017; Svensson et al., 2018;

Tschopp et al., 2015) The original wording of the program, as it appeared in the farmer questionnaire, is in Appendix 1.

The description of the program was extensive and consisted of two pages. This would ensure that all participants had a similar understanding of VHHM. It consisted of three main sections: a definition of VHHM, the goals it comprises, and implementation procedures on the farm with the services included. In a VHHM, the veterinarian is actively involved in the management of the farm. He or she visits farms not only when animals are sick, but every two weeks. Numerous preventive measures are implemented on the farm to prevent animals from becoming sick in the first place. This should result in lower costs for the farmer. At the same time, it is intended to reduce the negative impact on society, as diseases do not arise in the first place and do not have to be treated with antibiotics, for example.

A hypothetical scenario presented to the farmers was embedded in the political framework of direct payments and incentive-based voluntary programs in Switzerland. Swiss farmers are used to this type of program, as similar programs for animal welfare have been implemented since the 1990s. Under the proposed program, subsidies will reduce the cost of VHHM that farmers must pay themselves.

4.2.5 Elicitation method: discrete choice questions

A closed-ended format was chosen as the elicitation format because it has several advantages over open-ended questions. The single-bounded discrete choice (SBDC) question was preferred to the double-bounded discrete choice (DBDC) format, which is also widely used. While SBDC has lower statistical efficiency, the DBDC may increase item non-response and strategic behavior in subsequent responses; hence, there can also be some bias in going from an SB to a DB format (Herriges and Shogren, 1996). There is evidence that responses to the second bid are inconsistent with those to the first bid (Bateman et al., 2001; Carson and Groves, 2007)

Due to the problems associated with DBDC, a dual approach was avoided. However, in order not to be completely at the mercy of the SBDC problem of low statistical efficiency, the following strategy was chosen. Because in the pretest and pilot study a relatively high share of respondents having no interest at all in taking part in the program was detected, this was also expected in the survey. Therefore, a follow-up asking respondents if they even had a willingness to participate was included. Applying this approach made it possible to apply the spike model introduced by Kriström (1997).

As Haab and McConnell (2002) mentioned, the selection of bids is of particular importance. A carefully selected bid vector can considerably improve the efficiency of WTP estimates. Discussions with the few veterinarians already offering VHHM in Switzerland resulted in average costs for the proposed hypothetical VHHM setting of CHF 120 per cow per year (in 2018, one Swiss franc [CHF] corresponded to €0.87 and US$1.02; https://data.snb.ch). The costs are based on cow and not farm level to address different farm sizes. The bid levels were chosen in light of (i) discussions with policy makers on likely reimbursement levels, (ii) discussion of likely farmer WTPs in the focus group, and (iii) piloting of bid values in the questionnaire. This resulted in the four bid levels of CHF 24, 48, 72, and 96 per cow and year, being equivalent to reimbursement levels of 20%, 40%, 60%, and 80% of the average costs for VHHM. Bid levels were distributed across the sample, with only one of these bid levels randomly assigned to each farmer. Appendix 2 displays the complete wording of the proposed hypothetical policy with its corresponding DC and follow-up questions.

4.2.6 Statistical model of contingent valuation responses

4.2.6.1 Statistical model

In the questionnaire, participants were not directly asked about their willingness to pay for the veterinary herd health management program. Instead, they had to state whether they would participate at a previously determined amount (t_i, that varies randomly across individuals). That is, survey responses were not themselves a direct measure of the farmers' WTP. However, WTP can be derived from the survey responses through statistical analysis (Carson and Hanemann, 2005).

<u>Single-bounded discrete choice model</u>

As a starting point of the statistical analysis, the probability of getting a yes or no answer to the discrete-choice question in the questionnaire is modeled (y_i = 0 if the individual answers no and y_i = 1 if the individual answers yes) Assume that a farmer is presented a bid level t_i for participating in VHHM. It is expected that the individual will answer yes when his WTP is greater than the suggested bid level., i.e., when $WTP_i > t_i$. The probability of obtaining a 'yes' response is therefore given by

$$Pr(response\ is\ "yes") = Pr\ (WTP_i > t_i)$$

This probability statement is still very general. In order to be able to use it for parametric estimation, two assumptions have to be made. The first one concerns the functional form of the WTP function. Following the practice of former studies, let the WTP function be linear in attributes with an additive stochastic preference term

$$WTP_i(z_i, u_i) = z_i\gamma + u_i \tag{1}$$

where z_i is a vector of explanatory variables, γ is a vector of parameters and u_i is an error term.

By this assumption the probability statement can be modified to:

$$\begin{aligned} Pr(y_i = 1|z_i) &= Pr(WTP_i > t_i) \\ &= Pr(z_i\gamma + u_i > t_i) \\ &= Pr(u_i > t_i - z_i\gamma) \end{aligned}$$

The second assumption that must be made concerns the distribution of error values. These are assumed to be independently and identically distributed (IID) with mean zero. This suggests the use of the normal or the logistic distribution. With this assumption, the probability model can be further refined.

First, we assume that the errors are normally distributed ($u_i \sim N(0; \sigma^2)$). In the first step, it is necessary to convert $u_i \sim N(0; \sigma^2)$) to a standard normal ($N(0; 1)$)). Let $v_i = u_i/\sigma$, then $v_i \sim N(0; 1)$, and

$$Pr(y_i = 1|z_i) = Pr(u_i > t_i - z_i\gamma)$$

$$= Pr(v_i > \frac{t_i - z_i\gamma}{\sigma})$$

$$= 1 - \phi(\frac{t_i - z_i\gamma}{\sigma})$$

$$= \phi(z_i \frac{\gamma}{\sigma} - t_i \frac{1}{\sigma}) \qquad (2)$$

where ϕ(x) is the the cumulative standard normal, i.e. the probability that a unit normal variate is less than or equal to x. This is the probit model. There are two ways to estimate this model. The first option is to use this equation and maximum likelihood solving for γ and σ. The second option is to use a statistics program that has a direct command for the probit model. In Stata (StataCorp, 2013), for example, this would be the *probit* command. By this, we get estimates for γ/σ and $1/\sigma$. The results we get from the probit command are: $\hat{a} = \frac{\gamma}{\hat{\sigma}}$ (the vector of coefficients associated to each one of the explanatory variables) and $\widehat{ß} = - \frac{1}{\hat{\sigma}}$ (the coefficient for the variable capturing the amount of the bid).

Having these estimates, the next step is to get values for the expected willingness to pay, which is defined for (1) as

$$E(WTP_i|z_i, \gamma) = z_i\gamma$$

The true value of γ is not known. However, one can use â and $\widehat{ß}$ to estimate it. Rewriting the formulas for â and $\widehat{ß}$ and substituting yields

$$\hat{\gamma} = - \frac{\hat{a}}{\hat{\beta}} . \qquad (3)$$

If a logistic distribution is assumed for the error terms, derivations steps are similar to (2). Therefore, the derivation path is not shown again. The main difference is that the probability that a variate is less than or equal to x is not given by the cumulative standard normal ϕ(x), but by $(1+\exp(-x))^{-1}$ in the standard logistic case.

The equivalent formula to (2) in the logistic case is therefore

$$Pr(y_i = 1|z_i) \;=\; [\,1 + exp(-(z_i \frac{\gamma}{\sigma} - t_i \frac{1}{\sigma}))]^{-1} \qquad (4)$$

When calculating with Stata, the logit command is used instead of the probit command. The calculation of the E(WTP) is also performed with (3).

Using â and $\widehat{ß}$, (2) and (4) can also be represented more conveniently as

$$Pr(y_i = 1|z_i) \;=\; \phi(a - ß\, t_i) \qquad (2)'$$

and

$$Pr(y_i = 1|z_i) \;=\; [\,1 + exp(-(a - ßt_i))]^{-1} \qquad (4)'$$

<u>Spike model</u>

In the spike model, the follow-up question from the questionnaire is used. This was asked to the farmers who answered in the negative to the first question with the corresponding bid level. They were asked if they had a WTP of zero. This left a first group that actually had a WTP of zero and a second group that had a positive WTP but one below the bid level.

The WTP was again assumed to be distributed as a logistic on the positive axis. This leads to a cumulative WTP distribution[1] that is (Kriström, 1997)

$$G_{WTP}(t) = \begin{cases} [1+\exp(a-\beta t)]^{-1} & \text{if } t > 0 \\ [1+\exp(a)]^{-1} & \text{if } t = 0 \\ 0 & \text{if } t < 0 \end{cases}$$

Thus, there is a jump discontinuity – a spike – at zero (Kriström, 1997). Parameters can be estimated by maximum likelihood method. The spike is defined by $[1+\exp(a)]^{-1}$. Mean WTP in the spike is defined as (Yoo and Kwak, 2009)

$$E(WTP) = (1/b)\ln[1+\exp(a)]$$

Statistical analysis

All calculations were performed using the statistical software Stata (StataCorp, 2013)

<u>Single-bounded discrete choice model</u>

For the single-bounded discrete choice model, a probit or logistic regression could have been performed. As Haab and McConnell, 2002 states, the differences between both are slight and the distributions typically yield similar ratios of parameter estimates. Therefore, we decided for logistic regression. The independent variable was the response to the question whether they would

---

[1] Be aware that this is the cumulative WTP distribution and not the probability model of a yes-answer as described in formula (2)'. This explains the difference in the sign.

participate in the VHHM for a given bid level (y_i = 0 if the individual answers no and y_i = 1 if the individual answers yes). The only independent variable used was the bid level t_i. For the calculation, the Stata command logit was used. Subsequently, the estimated mean value was calculated by dividing the estimated constant through the coefficient for the variable capturing the amount of the bid (as elaborated in (3)).

Spike Model

For the spike model, the package Spike was used (Azevedo, 2010) . Three variables are entered into the model. The first variable distinguishes between individuals who have a willingness to pay of zero and those who have a willingness to pay greater than zero. This information is obtained by the discrete-choice question with follow up. This determines the spike at WTP=0. The second variable indicates for the individuals who have a willingness to pay greater than zero, whether they would participate in the VHHM at the amount suggested to them. This determines the parameter of the logistic function in the positive region of the WTP. The third variable is the bid level t_i .

Confidence intervals

To quantify the uncertainty associated with the estimation of WTP, a Monte Carlo simulation technique of Krinsky and Robb (1986) was applied[2]. The goal was to

---

[2] The best approach to determine the confidence intervals in a DC approach is a simulation. The reason is that willingness to pay will not be normally distributed, even when the parameters are (For a more detailed explanation of this fact, please see (Haab and McConnell, 2002), p.110). The Krinsky and Robb method is based on taking a large number of draws from a multivariate

determine the 95% confidence interval. 5000 draws were performed. Lower and upper limits of the 95% confidence interval are given by the 126th and 4875th sorted estimates of simulated WTP. The calculations were performed using the Stata module "WTP“ (Hole, 2007).

Characteristics of farmers with WTP = 0

To determine the characteristics of the differences between the group with a WTP of zero and a WTP of greater than zero, logistic regression was performed. The first variable distinguished between individuals who have a willingness to pay of zero (coded as 0) and those who have a willingness to pay greater than zero (coded as 1). As dependent variables, 11 variables were used, which are described in Appendix 3. For the variable *age*, an additional interaction term age^2 was included in the model.

normal distribution with means given by the estimated coefficients and covariance given by the estimated covariance matrix of the coefficients (Hole, 2007a). Based on N draws taken from the joint distribution of the coefficients, R simulated values of WTP are calculated(Hole, 2007a). These R values can then be used to calculate the percentiles of the simulated distribution reflecting the desired level of confidence(Hole, 2007a). Confidence intervals calculated in this way are also called percentile intervals (Efron and Tibshirani, 1993). For the number of draws, we follow the recommendation of Haab (2002) with 5000, which is also implemented in Kwak (2009).

4.3 Results

4.3.1 WTP responses

The online questionnaire was completed by 217 farmers, and 268 returned the paper-and-pencil questionnaire (n=485), resulting in a response rate of 30.3%.

Farmers' responses to the discrete choice question are displayed in Table 1. The three categories represent the responses to the first and follow-up question, where "yes" indicates a yes to the first question, "no-yes" stands for no to the first question and yes to the second, which was if there is a willingness at all to participate in the program. The "no-no" category represents farmers who refused to participate, independently of the price. In all, 156 respondents (32.2% of the sample) answered "yes" to the first question with the associated bid amount and 329 respondents (67.8%) answered "no." Of these 329 respondents, 258 indicated that they had no WTP at all for VHHM. With increasing bid levels, there was a monotonic decrease in agreement. This is consistent with economic theory. Furthermore, it is apparent that a large proportion of farmers were not "in the market" and refused to participate. This already suggests that a spike model (Kriström, 1997) may be needed to avoid biased mean WTP estimates.

Ch.4 Table 1. Descriptive statistics of contingent valuation responses

Bid level		**CHF 24**	**CHF 48**	**CHF 72**	**CHF 96**		Sub-total	Total
Respondents assigned to each bid level (n, %)		131 27.0%	106 21.9%	113 23.3%	135 27.8%			485 100%
Response to discrete choice question[1] and follow-up[2]	yes[1]	55 42.0%	43 40.6%	32 28.3%	26 19.3%		156 32.2%	485 100%
	no[1] - yes[2]	6 4.6%	18 17.0%	15 13.3%	32 23.7%		71 14.6%	
	no[1] - no[2]	70 53.4%	45 42.5%	66 58.4%	77 57.0%		258 53.2%	

[1] "Suppose your veterinarian with special training and experience offered a VHHM charging CHF 120 per cow per year (farm visits approx. every two weeks; including: advice, routine examinations and visits; not including: pharmaceuticals and treatment of sick animals). The state would bear 20/40/60/80 % of these costs. You would still have to pay CHF 24/48/72/96 per cow and year. In this case, would you opt for a

VHHM?"

[2] "Do you even have a willingness to participate and to pay for this program?"

4.3.2 Estimation results

Table 2 describes the estimation results. All parameters in the spike model are statistically significant at the 1% level. In the SBDC model, the bid level parameter is significant. The Wald statistic shows that both equations are different from zero at the 1% level of statistical significance. The spike has a value of 0.53, which corresponds to the proportion of farmers who have no willingness to pay shown in Table 1. The SBDC model yields an estimated mean of CHF 10.47. For the spike model, the estimated mean WTP is CHF 57.96.

Table 2 also reports the 95 % confidence intervals for the point estimates for both models.~~,~~ A comparison of the confidence intervals of the two models shows that they are narrower in the spike model than in the SBDC model. This shows that the inclusion of the information from the follow-up question whether a WTP is present at all reduces the standard error of the mean and makes the confidence interval fairly tight. These results strongly support the use of the spike model in estimating WTP.

Figure 1 shows the probability of a "yes" answer as a function of the amount in the spike model[3]. For an amount of CHF 24 (80% of the costs are covered), the proportion of yes answers is 40.4%. At CHF 96 (20% of the costs are covered), this proportion is 23.6%.

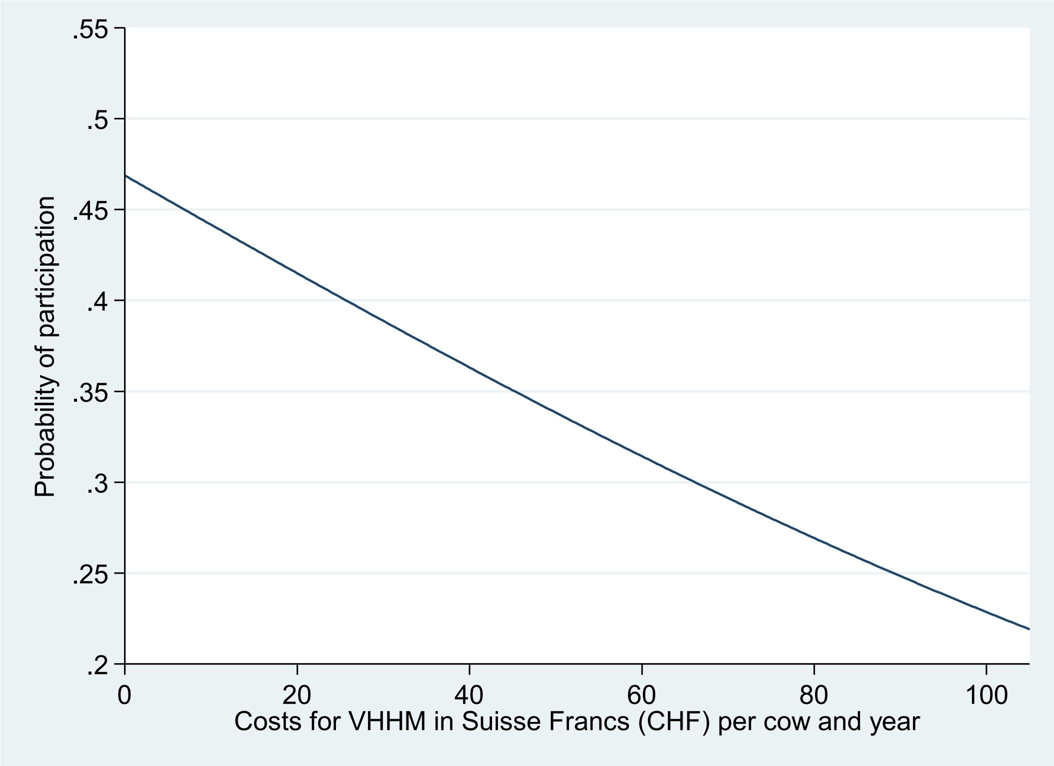
Ch.4 Table 2. Estimation results of single-bounded discrete choice and spike models

Variable	Single-bounded discrete choice model	Spike model
Constant	0.1633	-0.1253
Bid	-0.0155 **	0.0109**
Spike		0.5313**
Wald statistics	18.52**	83.50**
Mean WTP (CHF)	10.47	57.96
95% CI	-29.83, 28.19	45.31, 70.61
N	485	485

** Indicates statistical significance at the 1% level

[3] As described, in the present case the use of the spike model makes more sense than the single bounded discrete choice model. Therefore, the figure is only shown for the spike model.

Ch.4 Figure 1. Effect of costs for VHHM on probability of participation



4.3.3 Exploring the characteristics of WTP = 0

Over half the farmers indicated no willingness to pay for VHHM. It may be of interest to veterinarians and policy makers to know the characteristics of this group. For this purpose, a logistic regression was performed. Farmers with a WTP greater than zero were coded as 1, and farmers with no WTP were coded as 0.[4] Twelve farm and farmer characteristics were used as independent variables. These are presented in Appendix 3 with more detailed descriptions and descriptive statistics. Table 3 describes the results of the logistic regression. For age, a quadratic relationship is found at the 5% level of statistical significance. To illustrate this, the predictive margins for different age groups are plotted in Figure 2. Up to age 45, the probability increases, after which it decreases again. In addition, a correlation with previous veterinary costs is shown at the 1% level of statistical significance. Another statistically significant correlation at the 1% level of statistical significance is shown for the attitude question that VHHM is only suitable for farms having problems.

---

[4] The question arises whether this is not an unnecessary loss of information and why the WTP is not predicted as a continuous variable. This would be possible by using the information and estimates from the single-bounded discrete-choice model. Then it would be possible to predict WTP as continuous value. However, the fact that over half of the farmers did not express a willingness to pay argues against this. As stated in section 3.2, it makes more sense to use the results from the spike model. However, this precludes running a simple linear regression with the prediction as WTP as continuous value because we have jump discontinuity. To further use the results from the spike model, there are two possibilities: To be able to include all observations, there must be a 0/1 distinction. However, this leads to a loss of information. The second possibility is to include only the observations greater than zero. These are only half of the observations, but then the variables can be made continuous. However, the standard errors are also larger by the few observations. We present here only the results for the first option.

Ch.4 Table 3. Estimation results of logistic regression

	Odds Ratio	95 % CI		p-value
		Lower	Upper	
Farmer's age	1.33	1.02	1.73	0.03
Farmer's age^2	1.00	0.99	1.00	0.03
Organic farming	0.54	0.25	1.13	0.10
Plain zone	Ref.			
Hilly zone	0.89	0.43	1.81	0.74
Mountain zone I	0.60	0.28	1.27	0.18
Mountain zone II	0.53	0.23	1.22	0.13
Mountain zone III	0.51	0.17	1.56	0.24
Mountain zone IV	0.14	0.01	1.29	0.08
Number of cows	1.01	0.99	1.03	0.51
Milk yield	0.99	0.76	1.28	0.91
Veterinary costs[a]	1.00	1.00	1.01	0.01
Opinion problem[b]	0.63	0.50	0.78	<0.001
Opinion time[c]	0.87	0.68	1.12	0.29
Opinion vet[d]	1.09	0.85	1.40	0.49
Opinion large herds[e]	0.85	0.70	1.03	0.09
Opinion vet training[f]	0.97	0.78	1.22	0.81
Constant	0.01	0.00	4.42	0.14
N	326			

[a] Veterinary costs in 2018 per cow and year

[b] Opinion on statement: “A VHHM only suits farms having problems.” (5-point Likert scale: 1≙Strongly disagree, 5≙Strongly agree)

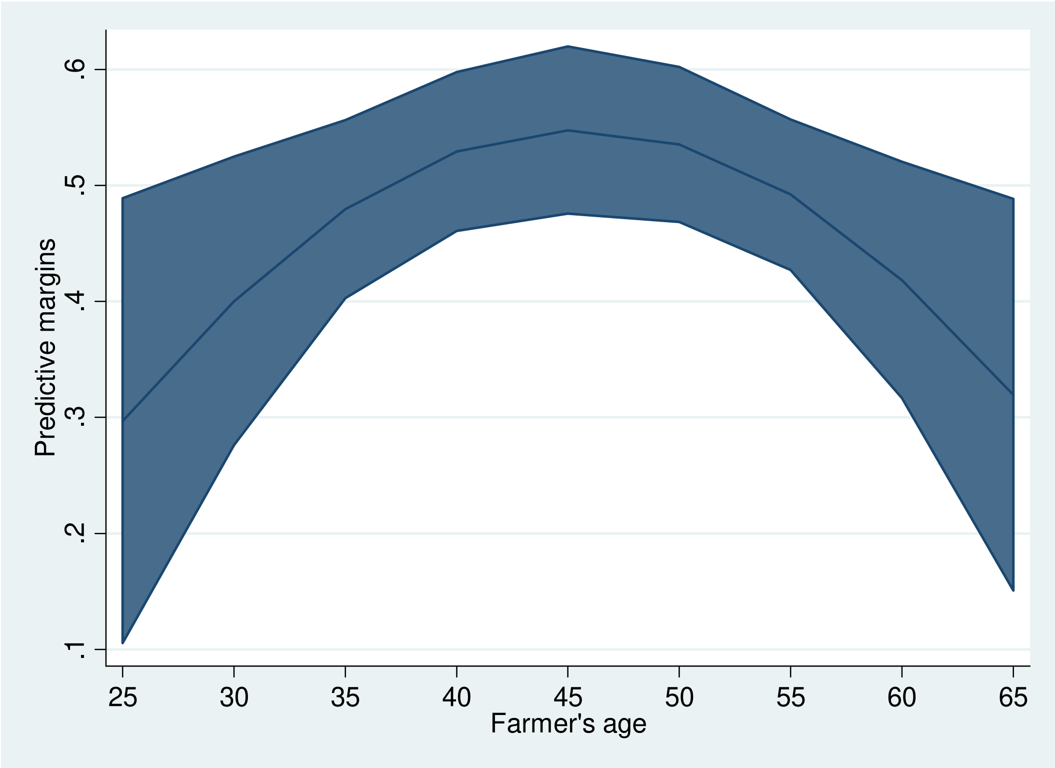
[c] Opinion on statement: “A VHHM is very time-consuming.” (5-point Likert scale: 1≙Strongly disagree, 5≙Strongly agree)

[d] Opinion on statement: “A veterinarian does not understand enough about practical dairy farming to give me additional advice.” (5-point Likert scale: 1≙Strongly disagree, 5≙Strongly agree)

[e] Opinion on statement: “A VHHM only suits farms with large herds.” (5-point Likert scale: 1≙Strongly disagree, 5≙Strongly agree)

[f] Opinion on statement: “A veterinarian is primarily trained for the treatment of individual animals, not for the care of an entire herd.” (5-point Likert scale: 1≙Strongly disagree, 5≙Strongly agree)

Ch.4 Figure 2. Predictive margins with 95% confidence interval of the effect of farmer's age on belonging to group with positive willingness to pay for VHHM



4.4 Discussion and concluding remarks

Through the present study, data on farmer willingness to pay for VHHM are available for the first time. Previous WTP studies in the field of veterinary services have been conducted only in developing countries (Baba and Ogungbile, 2000; Bardhan, 2010; Kathiravan and Thirunavukkarasu, 2008). However, due to the different economic structures, the results cannot be transferred.

That farmers have a problem with VHHM costs has been shown by previous studies (Derks et al., 2012; Gerber et al., 2020; Hool et al., 2020; Svensson et al., 2018). This study fills the gap of how much farmers are willing to pay for VHHM and how many farmers have positive WTP in the first place. Based on the willingness to participate, the spike model seems more appropriate than the SBDC for evaluating average WTP. At CHF 56 per cow per year, the average WTP is below the current cost, which is about CHF 120. This suggests that a subsidy may well be appropriate and would contribute to the spread of VHHM. The results show that the amount of the subsidy does play a role. However, determining the level of subsidy remains a political decision. Policy makers must decide whether increasing the participation rate is worth the additional cost.

In principle, voluntary approaches are more flexible in terms of legislation and can also be effective at lower costs, provided that farmers are willing to participate (Segerson, 2013). This willingness to participate in the proposed program is present in about half of the farmers. This reduces the potential overall effects of the program. A voluntary program as planned would thus reach its limits.

A clear difference between farms with no WTP and positive WTP is above all the attitude that VHHM is only suitable for farms with problems and thus already sick animals. Farmers still see the veterinarian as someone who cures animals. However, VHHM is just a concept that stands for preventive measures before animals are sick. In order to make VHHM more accepted, education could be important. This could help farmers understand the concept and the benefits that come with it.

Livestock disease can provoke high private and social costs (Jarvis and Valdes-Donoso, 2018). This shows the importance of animal health management and livestock disease control. It is above all the private task of livestock keepers to ensure that their animals are kept healthy. Indeed, they have already taken many measures to prevent animals from falling ill (Svensson et al., 2018)). However, purely private solutions do not always lead to a social welfare optimum. For example, in the case of vaccination, externalities can lead to a situation where farmers are likely to underinvest in private disease control measures (Beach et al., 2007; Gramig and Horan, 2011; Rat-Aspert and Fourichon, 2010; Zilberman et al., 2012), since vaccination helps a region become disease-free, while no vaccination contributes to disease transmission. Another externality can be seen in the problem of antibiotic resistance. The use of antibiotics carries with it the risk that resistance will develop. However, this emerging resistance is not necessarily only a problem for the farm using the antibiotic, but can also be a threat to other farms, which is why antibiotic resistance can be framed as an externality. In addition, information asymmetries associated with livestock disease control can lead to adverse selection and moral hazard (e.g., Gramig et al., 2009; Hennessy and Wolf, 2015; Sok et al., 2018). Public intervention may be justified when these market failures occur. Further, studies seeking to evaluate the success of VHHM mainly see a positive effect of VHHM on animal health outcomes and farm economics (Duval et al., 2018; Hässig et al., 2010; Ifende et al., 2014; Kreausukon et al., 2004; Kristensen and Enevoldsen, 2008; Pendl et al., 2017; Speksnijder et al., 2017; Tschopp et al., 2015).

The present study provides policy makers with an ex-ante basis for decision-making. It allows them to estimate the level of uptake the program would have and whether it would be worthwhile to implement it. They can also base the level of subsidy on the results of the study.

References

Azevedo, J. P. (2010). SPIKE: Stata module to allow for a zero willingness to pay Statistical Software Components S457126, Boston College Department of Economics. Statistical Software Components S457126, Boston College Department of Economics.

Baba, K. M. and Ogungbile, A. O. (2000). Demand of Fulani pastoralists for veterinary services in north-western Nigeria. Nigerian Journal of Animal Science, 3(2). https://doi.org/10.4314/tjas.v3i2.49756

Bard, A. M., Main, D. C. J., Haase, A. M., Whay, H. R., Roe, E. J., & Reyher, K. K. (2017). The future of veterinary communication: Partnership or persuasion? A qualitative investigation of veterinary communication in the pursuit of client behaviour change. PLoS ONE, 12(3). https://doi.org/10.1371/journal.pone.0171380

Bardhan, D. (2010). Factors influencing farmers' willingness to pay for animal health services and preference for private veterinary practitioners. Indian Journal of Animal Sciences, 80, 790–797.

Bateman, I. J., Langford, I. H., Jones, A. P., & Kerr, G. N. (2001). Bound and path effects in double and triple bounded dichotomous choice contingent valuation. Resource and Energy Economics, 23(3), 191–213. https://doi.org/10.1016/S0928-7655(00)00044-0

Beach, R. H., Poulos, C., & Pattanayak, S. K. (2007). Farm economics of bird flu. Canadian Journal of Agricultural Economics/Revue Canadienne d'agroeconomie, 55(4), 471–483. https://doi.org/10.1111/j.1744-7976.2007.00103.x

Bennett, R., & Balcombe, K. (2012). Farmers' willingness to pay for a tuberculosis cattle vaccine. Journal of Agricultural Economics, 63(2), 408–424. https://doi.org/10.1111/j.1477-9552.2011.00330.x

Bundesamt für Landwirtschaft BLW, 2018. Vernehmlassung zur Agrarpolitik ab 2022 (AP22+) Erläuternder Bericht. https://www.blw.admin.ch/dam/blw/de/dokumente/Politik/Agrarpolitik/AP22/Erl%C3%A4uternder_Bericht_d.pdf.download.pdf/Erl%C3%A4uternder_Bericht_d.pdf (accessed 05 March 2023)

Carson, R. T. and Groves, T. (2007). Incentive and informational properties of preference questions. Environmental and Resource Economics, 37(1), 181–210. https://doi.org/10.1007/s10640-007-9124-5

Carson, R. T. and Hanemann, W. M. (2005). Contingent valuation. In Handbook of Environmental Economics (vol. 2, pp. 821–936). Elsevier. https://doi.org/10.1016/S1574-0099(05)02017-6

Derks, M., van Werven, T., Hogeveen, H., & Kremer, W. D. J. (2013). Veterinary herd health management programs on dairy farms in the Netherlands: Use, execution, and relations to farmer characteristics. Journal of Dairy Science, 96(3), 1623–1637. https://doi.org/10.3168/jds.2012-6106

Derks, M., van de Ven, L. M. A., van Werven, T., Kremer, W. D. J., & Hogeveen, H. (2012). The perception of veterinary herd health management by Dutch dairy farmers and its current status in the Netherlands: A survey. Preventive Veterinary Medicine, 104(3), 207–215. https://doi.org/10.1016/j.prevetmed.2011.12.019

Duval, J. E., Bareille, N., Fourichon, C., Madouasse, A., & Vaarst, M. (2016). Perceptions of French private veterinary practitioners' on their role in organic dairy farms and opportunities to improve their advisory services for organic dairy farmers. Preventive Veterinary Medicine, 133, 10–21. https://doi.org/10.1016/j.prevetmed.2016.09.008

Duval, J. E., Bareille, N., Madouasse, A., de Joybert, M., Sjöström, K., Emanuelson, U., … Fourichon, C. (2018). Evaluation of the impact of a herd health and production management programme in organic dairy cattle farms: A process evaluation approach. Animal, 12(7), 1475–1483. https://doi.org/10.1017/S1751731117002841

Efron, B. and Tibshirani, R. (1993). An introduction to the bootstrap. New York: Chapman & Hall.

Ellis, E. (2017). Farmers' willingness to pay for crop insurance: Evidence from eastern Ghana. https://doi.org/10.22004/AG.ECON.292508

Enticott, G., Donaldson, A., Lowe, P., Power, M., Proctor, A., & Wilkinson, K. (2011). The changing role of veterinary expertise in the food chain. Philosophical Transactions of the Royal Society B: Biological Sciences, 366(1573), 1955–1965. https://doi.org/10.1098/rstb.2010.0408

Fahad, S. and Jing, W. (2018). Evaluation of Pakistani farmers' willingness to pay for crop insurance using contingent valuation method: The case of Khyber Pakhtunkhwa province. Land Use Policy, 72, 570–577. https://doi.org/10.1016/j.landusepol.2017.12.024

Gerber, M., Dürr, S., & Bodmer, M. (2020). Survey among livestock veterinarians from the Canton of Fribourg investigating the topics of herd-health management, counselling and the use of antimicrobial drugs. Schweiz Arch Tierheilkd, 162(1), 23–36. https://doi.org/10.17236/sat00240

Gramig, B. M. and Horan, R. D. (2011). Jointly determined livestock disease dynamics and decentralised economic behaviour: Jointly determined livestock disease dynamics. Australian Journal of Agricultural and Resource Economics, 55(3), 393–410. https://doi.org/10.1111/j.1467-8489.2011.00543.x

GST. (2020). GST_Positionspapier_Tieraerztliche_Bestandesbetreuung.pdf. Retrieved June 22, 2020, from https://www.gstsvs.ch/fileadmin/media/pdf/Positionspapiere/GST_Positionspapier_Tieraerztliche_Bestandesbetreuung.pdf

Haab, T. C. and McConnell, K. E. (2002). Valuing environmental and natural resources: The econometrics of non-market valuation. Edward Elgar Publishing.

Hall, J. and Wapenaar, W. (2012). Opinions and practices of veterinarians and dairy farmers towards herd health management in the UK. The Veterinary Record, 170(17), 441. https://doi.org/10.1136/vr.100318

Hässig, M., Kemper-Gisler, D., Liesegang, A., & Braun, U. (2010). Vergleich von Leistungsfähigkeit und tierärztlichen Kosten in landwirtschaftlichen Betrieben mit und ohne «Integrierte Tierärztliche Bestandesbetreuung» (ITB). Schweizer Archiv Für Tierheilkunde, 152(10), 470–476. https://doi.org/10.1024/0036-7281/a000107

Herriges, J. A. and Shogren, J. F. (1996). Starting point bias in dichotomous choice valuation with follow-up questioning. Journal of Environmental Economics and Management, 30(1), 112–131. https://doi.org/10.1006/jeem.1996.0008

Hole, A. R. (2007a). A comparison of approaches to estimating confidence intervals for willingness to pay measures. Health Economics, 16(8), 827–840. https://doi.org/10.1002/hec.1197

Hole, A. R. (2007b). WTP: Stata module to estimate confidence intervals for willingness to pay measures. In Statistical Software Components. Boston College Department of Economics. Retrieved from https://ideas.repec.org/c/boc/bocode/s456808.html

Hool, N., Schüpbach-Regula, G., & Thomann, B. (2020). Livestock management and veterinary services for cattle and pigs in Switzerland. Schweiz Arch Tierheilkd, 162(5), 293–306. https://doi.org/10.17236/sat00258

Ifende, V. I., Derks, M., Hooijer, G. A., & Hogeveen, H. (2014). Financial aspects of veterinary herd health management programmes. Veterinary Record, 175(9), 224–224. https://doi.org/10.1136/vr.102183

Jarvis, L. S. and Valdes-Donoso, P. (2018). A selective review of the economic analysis of animal health management. Journal of Agricultural Economics, 69(1), 201–225. https://doi.org/10.1111/1477-9552.12131

Kathiravan, G. and Thirunavukkarasu, M. (2008). Willingness to pay for contract health care services in dairy animals: A payment card study. Iranian Journal of Veterinary Research, 9(1), 65–71. https://doi.org/10.22099/ijvr.2008.524

Komives, K., Bank, W., Foster, V., Halpern, J., Wodon, Q., & Staff, W. B. (2005). Water, electricity, and the poor: Who benefits from utility subsidies? World Bank Publications.

Kreausukon, K., Punyapornwitthaya, V., Kattapan, P., & Suriyasathaporn, W. (2004). A herd health management program resulted in decreased days open in first lactating cows in northern Thailand. Journal of Dairy Science, 87, 373.

Kristensen, E. and Enevoldsen, C. (2008). A mixed methods inquiry: How dairy farmers perceive the value(s) of their involvement in an intensive dairy herd health management program. Acta Veterinaria Scandinavica, 50(1), 50. https://doi.org/10.1186/1751-0147-50-50

Kriström, B. (1997). Spike models in contingent valuation. American Journal of Agricultural Economics, 79(3), 1013–1023. https://doi.org/10.2307/1244440

Kruif, A. and Opsomer, G. (2004). Integrated dairy herd health management as the basis for prevention. Vlaams Diergeneeskundig Tijdschrift, 73, 44–52.

Lievaart, J., Noordhuizen, J., Buckley, D., & Van Winden, S. (2008). The marketing of herd health and production management services on Dutch dairy farms: Perceptions of dairy farmers and their veterinary surgeons. Irish Veterinary Journal, 61(10), 668–676. https://doi.org/10.1186/2046-0481-61-10-668

Mutaqin, D. J. and Usami, K. (2019). Smallholder farmers' willingness to pay for agricultural production cost insurance in rural West Java, Indonesia: A contingent valuation method (CVM) approach. Risks, 7(2), 69. https://doi.org/10.3390/risks7020069

Padhan, R. and Prabheesh, K. P. (2021). The economics of COVID-19 pandemic: A survey. Economic Analysis and Policy, 70, 220–237. https://doi.org/10.1016/j.eap.2021.02.012

Pendl, W., Jenny, B., Torgerson, P. R., Spring, P., Kümmerlen, D., & Sidler, X. (2017). Effect of herd health management on the prevalence of Postpartum Dysgalaktie Syndrome (PPDS) and the treatment incidence. Schweiz Arch Tierheilkd, 159(2), 109–116. https://doi.org/10.17236/sat00105

Rat-Aspert, O. and Fourichon, C. (2010). Modelling collective effectiveness of voluntary vaccination with and without incentives. Preventive Veterinary Medicine, 93(4), 265–275. https://doi.org/10.1016/j.prevetmed.2009.11.004

Ruston, A., Shortall, O., Green, M., Brennan, M., Wapenaar, W., & Kaler, J. (2016). Challenges facing the farm animal veterinary profession in England: A qualitative study of veterinarians' perceptions and responses. Preventive Veterinary Medicine, 127, 84–93. https://doi.org/10.1016/j.prevetmed.2016.03.008

Segerson, K. (2013). When is reliance on voluntary approaches in agriculture likely to be effective? Applied Economic Perspectives and Policy, 35(4), 565–592. https://doi.org/10.1093/aepp/ppt030

Sok, J., van der Lans, I. A., Hogeveen, H., Elbers, A. R. W., & Oude Lansink, A. G. J. M. (2018). Farmers' preferences for bluetongue vaccination scheme attributes: An integrated choice and latent variable approach. Journal of Agricultural Economics, 69(2), 537–560. https://doi.org/10.1111/1477-9552.12249

Speksnijder, D. C., Jaarsma, A. D. C., van der Gugten, A. C., Verheij, T. J. M., & Wagenaar, J. A. (2015). Determinants associated with veterinary antimicrobial prescribing in farm animals in the Netherlands: A qualitative study. Zoonoses and Public Health, 62, 39–51. https://doi.org/10.1111/zph.12168

Speksnijder, D. C., Graveland, H., Eijck, I. A. J. M., Schepers, R. W. M., Heederik, D. J. J., Verheij, T. J. M., & Wagenaar, J. A. (2017). Effect of structural animal health planning on antimicrobial use and animal health variables in conventional dairy farming in the Netherlands. Journal of Dairy Science, 100(6), 4903–4913. https://doi.org/10.3168/jds.2016-11924

Speksnijder, D. C. and Wagenaar, J. A. (2018). Reducing antimicrobial use in farm animals: How to support behavioral change of veterinarians and farmers. Animal Frontiers, 8(2), 4–9. https://doi.org/10.1093/af/vfy006

StataCorp (Version 13). (2013). College Station, TX: StataCorp LP: Stata Statistical Software.

Svensson, C., Alvåsen, K., Eldh, A. C., Frössling, J., & Lomander, H. (2018). Veterinary herd health management–Experience among farmers and farm managers in Swedish dairy production. Preventive Veterinary Medicine, 155, 45–52. https://doi.org/10.1016/j.prevetmed.2018.04.012

Tschopp, A., Reist, M., Kaufmann, T., Bodmer, M., Kretzschmar, L., Heiniger, D., … van den Borne, B. H. P. (2015). A multiarm randomized field trial evaluating strategies for udder health improvement in Swiss dairy herds. Journal of Dairy Science, 98(2), 840–860. https://doi.org/10.3168/jds.2014-8053

Woodward, H., Cobb, K. and Remnant, J. (2019). The future of cattle veterinary practice: Insights from a qualitative study. Veterinary Record. https://doi.org/10.1136/vr.105321

Yoo, S.-H. and Kwak, S.-Y. (2009). Willingness to pay for green electricity in Korea: A contingent valuation study. Energy Policy, 37(12), 5408–5416. https://doi.org/10.1016/j.enpol.2009.07.062

Zhong, H., Qing, P., & Hu, W. (2016). Farmers' willingness to participate in best management practices in Kentucky. Journal of Environmental Planning and Management, 59(6), 1015–1039. https://doi.org/10.1080/09640568.2015.1052379

Zilberman, D., Sproul, T. W., Sexton, S., & Roland-Holst, D. (2012). The economics of zoonotic diseases: An application to avian flu. In D. Zilberman, J. Otte, D. Roland-Holst, & D. Pfeiffer (Eds.), Health and animal agriculture in developing countries (pp. 59–76). Springer New York. https://doi.org/10.1007/978-1-4419-7077-0_4

Appendix

Ch.4 Appendix 1. Description of VHHM as presented to farmers in the questionnaire

Hypothetical policy program: Financial contribution to Veterinary Heard Health Management (VHHM)

The Federal Government assumes part of the annual costs of the VHHM.

<u>What is the VHHM?</u>

Traditionally, the veterinarian is concerned mainly with curing sick animals. Within the framework of VHHM, veterinary activities are expanded. The veterinarian additionally supports animal owners in maintaining the health of their animals.

Together with the animal owner, the veterinarian looks into how o prevent animals from becoming ill in the future. To this end, the veterinarian offers company-specific advice and the development of appropriate measures.

In this way, costs that are usually incurred due to illnesses (e.g. for treatments, medication, loss of performance, etc.) can be reduced.

<u>Goals of the VHHM</u>

- To maintain and, where necessary, improve the health of individual animals and herds by
    - Development and strengthening of prophylactic measures
    - Regular diagnostics

    - Assessment and optimization of management, feeding and husbandry
    - Elimination of risk factors
- Higher profitability of milk production through
    - Reduction of direct costs (e.g. costs for treatment and medication)
    - Reduction of hidden costs (e.g. culling, number of inseminations, duration of the intercalving period, loss of performance and costs due to diseases such as mastitis, stuck or lameness)
    - Maintaining and, where appropriate, improving performance
- Early detection of subclinical diseases or performance-reducing factors through
    - Evaluation of performance data and regular diagnostics
    - This allows necessary treatments to be started early and/or prevents the spread to other animals
- Reduction of the usage of pharmaceuticals

<u>Implementation of the VHHM</u>

Step 1: Analysis of strengths and weaknesses of the farm

The veterinarian and the livestock keeper jointly determine the scope (frequency of visits, intensity of advice) and costs of the VHHM. An VHHM is always farm-specific. It is adapted to the different structures of farms and the preferences of livestock keepers.

Objectives are formulated and recorded. An action plan for maintaining animal health is drawn up, and the veterinary activities to be carried out are listed.

The achievement of the objectives and the implementation of the measures is checked by regular visits to the farm (e.g. every two or four weeks, adapted to individual requirements).

Through systematic, computer-supported data management, evaluation and interpretation, conclusions can be drawn on health status, performance parameters and drug consumption of individual animals or herds. This allows the documentation of what has been achieved and the planning of new goals.

The veterinarian in charge of the herd orders specific diagnostic measures, explains the laboratory findings to livestock keepers and derives necessary measures from them.

Systematic planning of routine veterinary work and routine examinations frees up resources that can be used to provide veterinary advice to livestock owners.

The close cooperation between the animal owner and the herd veterinarian creates a relationship of trust.

If necessary, other livestock experts (e.g. feeding, stable construction, technology) can be called in. This leads to a network of different service providers and consultants around the farm.

Ch.4 Appendix 2. Proposed hypothetical setting

Suppose your veterinarian with special training and experience offered a VHHM charging CHF 120 per cow per year (farm visits approx. every two weeks; including: advice, routine examinations and visits; not including: pharmaceuticals and treatment of sick animals).

The state would bear 20/40/60/80 % of these costs. You would still have to pay CHF 24/48/72/96 per cow and year. In this case, would you opt for a VHHM?

For respondents answering NO to the first question: first follow-up question:

Do you even have a willingness to participate and to pay for this program?

Ch.4 Appendix 3. Descriptive statistics of farm and farmer characteristics

Variable	Description	Unit	Mean	SD
Farmer's age	Farmer's age in 2018	Years	46.73	9.88
Organic farming	Dummy variable indicating involvement in organic farming	%	17.5	–
Main agricultural zone	Plain zone	%	39.9	–
	Hilly zone	%	17.5	–
	Mountain zone I	%	17.5	–
	Mountain zone II	%	15.3	–
	Mountain zone III	%	6.7	–
	Mountain zone IV	%	3.1	–

Number of cows	Number of cows on farm in 2018		28.70	17.49
Milk yield	Milk yield per cow and year < 6 000 ≙ 1 6 001–7 000 ≙ 2 7 001–8 000 ≙ 3 8 001–9 000 ≙ 4 >9000 ≙ 5	kg per cow and year	2.69	1.30
Veterinary costs	Veterinary costs in 2018	CHF/cow-year	177.58	113.44
	Opinion on statements:			
Opinion problem	“An VHHM only suits farms having problems.”	5-point Likert scale	3.03	1.34

Opinion time	"An ITB is very time-consuming."	1≙Strongly agree, 5≙Strongly disagree	3.68	1.11
Opinion vet	"A veterinarian does not understand enough about practical dairy farming to give me additional advice."		2.37	1.23
Opinion large herds	"An ITB only suits farms with large herds."		2.69	1.42
Opinion vet training	"A veterinarian is primarily trained for the treatment of individual animals, not for the care of an entire herd."		2.62	1.38

Chapter 5. Conclusion

This thesis examines the potential of voluntary programs to improve animal health and reduce the use of antibiotics. So far, voluntary programs in agriculture have mainly been investigated in the areas of environment and animal welfare. The topic of antibiotic reduction has been underrepresented in literature and policy practice.

Article 1 in Chapter 2 shows that 75% of the farms surveyed used antibiotics preventively and in addition, 65% of farms for therapeutic use. This demonstrates that there is a need for action. Farms that follow the principles of organic farming have a lower usage of antibiotics, while farmers which state that antibiotics are important for animal production have a higher usage rate. This shows that a change of the mindset is a prerequisite for antibiotic reduction.

Article 2 in Chapter 3 shows that the existing free-stall program “Particularly animal friendly stabling” has the potential to support lower antibiotic usage. Therefore, it could be adapted to increase participation rates. The advantage of this program is that it defines clear measures for husbandry conditions that apply to all farms and are also relatively easy to monitor. The concrete measures used in this program are just one example of a wide range of possible designs.

For example, programs that focus more strongly on the topic of biosecurity may also be conceivable. However, the disadvantage of these measures, which apply across all farms, is that the measures do not have an effect on all farms due to the multifactorial causes of diseases. This bears the risk that the state would be spending money without any effect.

Finally, Chapter 4 shows that the promotion of a Veterinary Herd Health Management Program, could be economically and medically reasonable, as a basic willingness to participate on the part of farmers is to be expected. However, the question that could not be answered conclusively is whether the farms with a high use of antibiotics would actually be reached and whether this would result in significant reductions overall. The possible effect also depends on the individual situation on the farms, the quality of the advice given by the veterinarians and also farmers' discipline in implementing the proposed measures. These are all factors that are much more difficult for the state to monitor than those in program designs as described in Article 2.

In principle, it seems obvious at first to apply the principle of voluntary approaches to antibiotic reduction and to reward reduction on farms. At closer look however, challenges arise. If the use of antibiotics is reduced without further measures being taken, there is a risk that sick animals will not be treated, thus jeopardizing animal welfare. To prevent this, it is possible to either combine the paid programs with massive controls or avoiding subsidizing the reduction of antibiotics, yet to promote measures that contribute to animal health. The risk is here that the effect on antibiotic reduction is not guaranteed and therefore one goal of the program may not be achieved. An additional factor that may influence the willingness to participate is that if one pays for a reduction, farms that are already doing well will be excluded.

All in all, this thesis is a first attempt to transfer the topic of voluntary programs to livestock disease control and antibiotic reduction. The questions answered make a first initial contribution. Nonetheless, since this field is yet very large and mostly unexplored, there is ample room for future research.

Chapter 6. References (Introduction)

Alvan, G., Edlund, C., Heddini, A., 2011. The global need for effective antibiotics—A summary of plenary presentations. Drug Resistance Updates 14, 70–76. https://doi.org/10.1016/j.drup.2011.01.007

Bennett, R., Balcombe, K., 2012. Farmers' Willingness to Pay for a Tuberculosis Cattle Vaccine: Farmers' Willingness to Pay for a Tuberculosis Cattle Vaccine. Journal of Agricultural Economics 63, 408–424. https://doi.org/10.1111/j.1477-9552.2011.00330.x

Derks, M., van de Ven, L.M.A., van Werven, T., Kremer, W.D.J., Hogeveen, H., 2012. The perception of veterinary herd health management by Dutch dairy farmers and its current status in the Netherlands: A survey. Preventive Veterinary Medicine 104, 207–215. https://doi.org/10.1016/j.prevetmed.2011.12.019

Dessart, F.J., Barreiro-Hurlé, J., van Bavel, R., 2019. Behavioural factors affecting the adoption of sustainable farming practices: a policy-oriented review. Eur Rev Agric Econ 46, 417–471. https://doi.org/10.1093/erae/jbz019

Gerber, M., Dürr, S., Bodmer, M., 2020. Survey among livestock veterinarians from the Canton of Fribourg investigating the topics of herd-health management, counselling and the use of antimicrobial drugs. Schweiz Arch Tierheilkd 162, 23–36. https://doi.org/10.17236/sat00240

Hool, N., Schüpbach-Regula, G., Thomann, B., 2020. Livestock management and veterinary services for cattle and pigs in Switzerland. SAT 162, 293–306. https://doi.org/10.17236/sat00258

Laxminarayan, R., 2006. Fighting Antibiotic Resistance – can economic incentives play a Role?, in: Oates, W.E. (Ed.), The RFF Reader in Environmental and Resource Policy. Resources for the Future, Washington, DC, pp. 289–292.

Mann, S., 2005. Konzeptionelle Überlegungen zur Neugestaltung des Direktzahlungssystems der schweizerischen Landwirtschaft auf der Basis der Tinbergen-Regel, FAT-Schriftenreihe / Agroscope Fat Tänikon, Eidgenössische Forschungsanstalt für Agrarwirtschaft und Landtechnik. Ettenhausen : agroscope FAT Tänikon.

Odermatt, B., Keil, N., Lips, M., 2018. Animal Welfare Payments and Veterinary and Insemination Costs for Dairy Cows. Agriculture 9, 3. https://doi.org/10.3390/agriculture9010003

Padhan, R., Prabheesh, K.P., 2021. The economics of COVID-19 pandemic: A survey. Economic Analysis and Policy 70, 220–237. https://doi.org/10.1016/j.eap.2021.02.012

Regula, G., Danuser, J., Spycher, B., Wechsler, B., 2004. Health and welfare of dairy cows in different husbandry systems in Switzerland. Prev Vet Med 66, 247–264. https://doi.org/10.1016/j.prevetmed.2004.09.004

Scheper, J., Holzschuh, A., Kuussaari, M., Potts, S.G., Rundlöf, M., Smith, H.G., Kleijn, D., 2013. Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss – a meta-analysis. Ecology Letters 16, 912–920. https://doi.org/10.1111/ele.12128

Segerson, K., 2013. When Is Reliance on Voluntary Approaches in Agriculture Likely to Be Effective? Applied Economic Perspectives and Policy 35, 565–592. https://doi.org/10.1093/aepp/ppt030

Sok, J., van der Lans, I.A., Hogeveen, H., Elbers, A.R.W., Oude Lansink, A.G.J.M., 2018. Farmers' Preferences For Bluetongue Vaccination Scheme Attributes: An Integrated Choice and Latent Variable Approach. Journal of Agricultural Economics 69, 537–560. https://doi.org/10.1111/1477-9552.12249

Svensson, C., Alvåsen, K., Eldh, A.C., Frössling, J., Lomander, H., 2018. Veterinary herd health management–Experience among farmers and farm managers in Swedish dairy production. Preventive Veterinary Medicine 155, 45–52. https://doi.org/10.1016/j.prevetmed.2018.04.012

Tschopp, A., Reist, M., Kaufmann, T., Bodmer, M., Kretzschmar, L., Heiniger, D., Berchtold, B., Wohlfender, F., Harisberger, M., Boss, R., Strabel, D., Cousin, M.-E., Graber, H.U., Steiner, A., van den Borne, B.H.P., 2015. A multiarm randomized field trial evaluating strategies for udder health improvement in Swiss dairy herds. Journal of Dairy Science 98, 840–860. https://doi.org/10.3168/jds.2014-8053

Umali, D.L., Feder, G., de Haan, C., 1992. The Balance between Public and Private Sector Activities in the Delivery of Livestock Services (No. 163), World Bank - Discussion Papers, World Bank - Discussion Papers. World Bank.

WHO, 2020. Global antimicrobial resistance and use surveillance system (GLASS) report: early implementation 2020. World Health Organization, Geneva.