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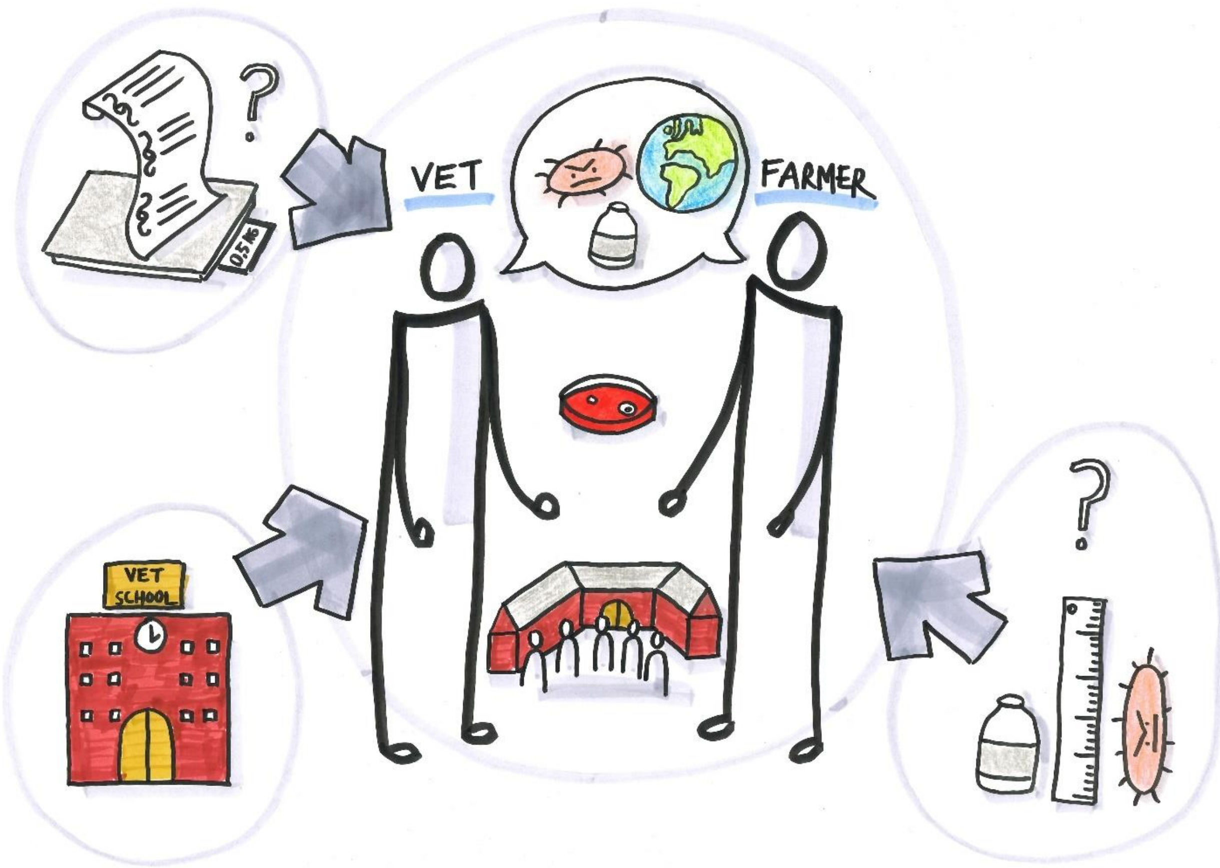
FACULTY OF HEALTH AND MEDICAL SCIENCES

Antimicrobial use in dairy cattle explored through mixed methods

Focusing on the farmer-veterinarian collaboration



PhD Thesis 2021 • Nanna Krogh Skjølstrup

This thesis has been submitted to the Graduate School of Health and Medical Sciences, University of Copenhagen, 30th December 2021

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Nanna Krogh Skjølstrup

Department of Veterinary and Animal Sciences
University of Copenhagen, Denmark

This thesis has been submitted to the Graduate School of Health and Medical Sciences, University of Copenhagen, 30th December 2021

Principal supervisor: Professor Anders Ringgaard Kristensen
Department of Veterinary and Animal Sciences
University of Copenhagen
Denmark

Co-supervisors: Assistant Professor Dorte Bay Lastein
Department of Veterinary and Animal Sciences
University of Copenhagen
Denmark

Professor Liza Rosenbaum Nielsen
Department of Veterinary and Animal Sciences
University of Copenhagen
Denmark

Assessment Committee: Professor Volker Krömker (Chairman)
Department of Veterinary and Animal Sciences
University of Copenhagen
Denmark

Professor Kristen K. Reyher
The Bristol Veterinary School
University of Bristol
United Kingdom

Professor Søren Østergaard
Department of Animal Science
Aarhus University
Denmark

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Preface and acknowledgements

"… An advising veterinarian is at a herd visit. The herd struggles with a high level of antimicrobial use. The veterinarian shows the farmer a list of ten improvement points that she has been working on for several days. The farmer hesitates at the sheer thought of working on all these areas at once; he would prefer a quick solution that does not require a great effort from him. He asks the veterinarian for some of that effective antimicrobial that he once had prescribed for a critically ill calf and asks whether "they can just start with that?" The veterinarian feels demotivated due to the lack of response to her list, and she is afraid of rejecting the farmer's request – what if it puts her in a bad standing with the farmer? In addition, she knows that her boss was the one who prescribed the broad-spectrum antimicrobials for the calf that time…"

This was the first text I wrote as part of this PhD project. It was inspired by my own working experience in veterinary practice and illustrates very well the starting point for my personal motivation to engage in this project. Driven by a curiosity to understand the motivation for change – in particular in relation to antimicrobial use – I eagerly jumped into this three-year long journey. My horizons have been broadened; I now understand that motivation for change is complex and difficult to describe, understand or influence. At the end of the day, some of the things that seem to be important are communication and a willingness to understand the perspectives of the person in front of you. I am grateful for the insights I have gained by conducting this PhD and in particular the entrance to the world of qualitative research, which has been a completely new but valuable encounter for me!

This PhD project was funded by the University of Copenhagen. I wish to thank my supervisors Anders Ringgaard Kristensen, Liza Rosenbaum Nielsen and Dorte Bay Lastein. Dorte, for always being there as my advisor, colleague and cheerful supporter, for your dedication to this topic and tireless commitment to your role as my supervisor. Liza, for always contributing useful and insightful advice, for your endless sense of perspective and overview of the writing process, and for always finding time for me. Anders, for your patience, helpfulness and for allowing me a small insight into your impressive knowledge about dynamic models. Furthermore, I wish to thank Leo for assisting me in statistical matters and for always being open minded and optimistic. Thank you to Mette Vaarst and Carsten Strøby Jensen for several fruitful collaborations. Your insights, reflections and experience into qualitative research have been very valuable!

I also wish to express my sincere thanks to all my colleagues and sparring partners at the University of Copenhagen, Aarhus University, Foulum, and Oniris, Nantes, France. Finally, a big thank you to all of the Danish farmers and practising veterinarians who have participated and contributed either as interviewees or "guinea pigs" in the Stable School study.

Frederiksberg, December 2021

Nanna Krogh Skjølstrup

List of manuscripts

List of manuscripts included in the thesis:

I. Nanna K. Skjølstrup, Liza R. Nielsen, Carsten S. Jensen and Dorte B. Lastein (2021). **Veterinary herd health consultancy and antimicrobial use in dairy herds.** In *Frontiers in Veterinary Science,* 2021. https://doi.org/10.3389/fvets.2020-547975.

II. Nanna K. Skjølstrup, Dorte B. Lastein, Carsten S. Jensen and Mette Vaarst (2021). **The antimicrobial landscape as outlined by Danish dairy farmers.** In *Journal of Dairy Science*, 2021. https://doi.org/10.3168/jds.2021-20552.

III. Nanna K. Skjølstrup, Mette Vaarst, Carsten S. Jensen and Dorte B. Lastein (2021). **Danish cattle veterinarians' perspectives on antimicrobial use: contextual and individual influencing factors.** In *Journal of Dairy Science,* 2021. https://doi.org/10.3168/jds.2021-20981.

IV. Nanna K. Skjølstup, Anders R. Kristensen, Leonardo V. de Knegt, Liza R. Nielsen and Dorte B. Lastein (2021). **A mixed methods approach to monitoring changes at Danish dairy farms during a veterinarian-facilitated Stable School to improve health and antimicrobial use.** Manuscript to be submitted.

V. Nanna K. Skjølstrup, Dorte B. Lastein, Leonardo V. de Knegt and Anders R. Kristensen (2021). **Using state space models to monitor and estimate the effect of interventions on treatment risk and milk yield in Danish conventional dairy farms.** Manuscript submitted and under revision for publication in *Journal of Dairy Science*.

Summary

The purpose of this thesis is to contribute with knowledge required to achieve rational antimicrobial use (AMU) in dairy cattle production with a specific focus on the potential to do so within the veterinary herd health consultancy (VHHC) setting. This is necessary so that we can continue to have effective treatment options for infectious diseases in animals and humans by minimising the development of antimicrobial resistance (AMR). The overall aim of this thesis is to investigate the potential for changing AMU attitudes and actions in dairy herds within the Danish VHHC context.

The aim was explored through a mixed methods approach. A literature review study examined internationally identified factors of relevance for AMU reduction among farmers and veterinarians within VHHC and used a socio-ecological model to frame the findings of the 39 included papers. In addition, qualitative interviews were conducted with 15 Danish dairy farmers and 16 cattle veterinarians to explore their AMU practices and attitudes in order to identify opportunities and barriers to achieving rational AMU. Furthermore, a longitudinal Stable School case study was conducted to investigate the potential of the Stable School concept to instigate a change in AMU, health and production at the five participating conventional dairy herds. The Stable School herds were further used as a basis to demonstrate how combining dynamic quantitative methods with qualitative interviews and observations can be useful when evaluating potential changes over time and thereby how Stable Schools can constitute an alternative to the classical VHHC.

The results showed that a variety of factors influence the AMU of veterinarians and farmers. Some of these factors can be addressed within the VHHC setting, whereas others influence the VHHC indirectly and are structural in character. The factors of relevance vary from person to person and country to country, and it is therefore important to understand how the specific factors interact and influence the actors within the VHHC to work towards AMU reduction. Therefore, veterinarians and farmers should take a person-specific approach in order to gain an understanding of what and how factors influence the individual's AMU. The influencing factors identified include social norms (i.e. the influence exerted by immediate peers such as veterinarians and/or farmers), AMR perceptions, treatment practices and beliefs, the level of AMU legislation, the availability of valid AMU research results and efficient diagnostic tools, and the VHHC framework.

Legislation was found to have a particular influence on veterinarians and farmers, intertwined with perceptions of and attitudes towards AMR under Danish conditions. Furthermore, veterinarians seemed to base their treatment choices largely on personal experience due to a lack of locally valid and relevant scientific evidence about the effect of specific AMU choices and objective diagnostic tools. Both veterinarians and farmers were found to be influenced by their social environment, either through a pressure to prescribe or as inspiration for their own AMU choices.

The results from the thesis suggest that work to change AMU within the VHHC context should focus on prioritising time for reflection and dialogue on AMR and AMU to understand and develop each other's points of view. That way, new incentives and motivation to achieve rational AMU can be initiated, and the chance to plan and implement AMU-related actions at a specific herd may follow. Stable Schools may be one approach to initiating such a reflective process, potentially followed by specific actions. This has previously been shown for Danish organic dairy herds, and this thesis now also supports the incentive in Danish conventional dairy herds. None of the herds in the Stable School investigated in this thesis were found to have reduced AMU during the evaluation period. However, a change in attitudes towards AMU practices was observed and the follow-up period may have been too short to detect an actual reduction or change in AMU. For the Stable School participants to achieve rational AMU, it was suggested that a specific common AMU-related goal should be set and the group should be facilitated in a way that allowed farmers with different learning modes and temperaments to benefit from participation.

A central part of planning and implementing AMU actions within the VHHC is quantitative evaluation of AMU to establish whether a reduction or refinement in AMU has been achieved. It was demonstrated that state space models can be used for within-herd AMU evaluation. However, the specific application should be carefully considered and combined with qualitative data. It may be necessary to halt the evaluation and repeat it later if the conditions are not ideal, i.e. if there are many concurrent changes ongoing in the herd.

This thesis addresses change in AMU in dairy cattle production within a VHHC context from several perspectives. Firstly, from a local perspective, which identifies barriers and influencing factors for changing AMU from the veterinarian and farmer perspective and supports discussions about ways to understand and incorporate this knowledge and instigate change in the VHHC. In addition, concrete tools for monitoring and testing interventions on AMU change are presented and discussed. Secondly, it is addressed from a structural perspective, with discussions about the influence from contextual factors, e.g. legislation and education, and their impact on future change in AMU within the Danish VHHC setting. These results can be used by different actors and stakeholders in the field of AMU, including farmers and their sector organisations, veterinarians and veterinary authorities under Danish conditions. Because the Danish context is described in detail, the results can be used in other countries with similar AMU-conditions.

Sammendrag

Formålet med denne afhandling er at bidrage til at fremme rationelt antibiotikabrug i mælkeproduktionen, så vi kan begrænse udviklingen i antibiotikaresistens og bevare muligheden for at behandle infektiøse lidelser hos både dyr og mennesker med antibiotika. Fokus er særligt rettet mod rådgivningssamarbejdet mellem dyrlægen og landmanden og mulighederne for at arbejde med rationelt antibiotikabrug i netop den kontekst. Således er det overordnede mål med afhandlingen at undersøge mulighederne for at ændre antibiotikaforbruget i den danske mælke-produktionen inden for den veterinære sundhedsrådgivnings rammer.

Dette blev undersøgt ved brug af trans-disciplinær forskningstilgang. Først udførtes et litteraturstudium, der havde til formål at undersøge hvilke faktorer der har betydning for dyrlæger og landmænds motivation for at reducere antibiotikaforbruget inden for sundheds-rådgivningsarbejdet på et internationalt plan. En socioøkonomisk model blev brugt for at skabe en syntese over de identificerede faktorer fra de 39 inkluderede artikler. Derefter blev kvalitative metoder taget i brug i interviewstudier af henholdsvis 15 danske mælkeproducenter og 16 dyrlæger fra kvægpraksis. Interviewene undersøgte interviewpersonernes tanker om og tilgange til antibiotikaanvendelse. Slutteligt blev et longitudinelt casestudium baseret på en enkelt staldskole gennemført. Her blev staldskolens potentiale for at initiere forandringer i antibiotika-anvendelse, sundhed og produktion på de fem deltagende besætninger undersøgt. Derudover blev brugen af kvalitative interviews og observationer i kombination med dynamiske kvantitative modeller til at evaluere disse forandringer undersøgt som et konkret rådgivningsværktøj i dyrlægepraksis.

Resultaterne viste, at dyrlæger og landmænds antibiotikabrug påvirkes af mange forskellige faktorer. Nogle af disse faktorer kan adresseres af dyrlægen og landmanden inden for rådgivningsarbejdet. Andre faktorer påvirker imidlertid rådgivningsarbejdet udefra og er af strukturel karakter. Hvilke faktorer, der har betydning for den enkelte dyrlæge eller landmænd, varierer fra person til person og fra land til land. Inden for et rådgivningssamarbejde med fokus på reduktion af antibiotikabrug er det derfor vigtigt at forstå hvilke faktorer, modparten er påvirket af og betydningen heraf. Dette opnås bedst ved at have en personspecifik tilgang til rådgivningsarbejdet. Et udvalg af de påvirkende faktorer er: sociale normer i form af nære relationers indflydelse på antibiotikaanvendelse, opfattelser af antibiotikaresistens, tilgange og holdninger til behandling, niveauet af antibiotikalovgivning, rammerne for veterinær sundheds-rådgivning og tilgængeligheden af forskningsresultater på passende behandlingsregimer og effektive diagnostiske værktøjer. Lovgivning var sammenflettet med opfattelser af og holdninger til antibiotikaresistens blandt danske dyrlæger. Derudover havde lovgivning en særlig indflydelse på dyrlæger og landmænd under danske forhold. Resultaterne viste også, at dyrlæger i høj grad baserer deres behandlinger på personlige erfaringer, fordi der mangler objektive diagnostiske værktøjer og valide evidensbaserede forskningsresultater på antibiotikaanvendelse, der er brugbare i en lokal besætningskontekst. Både dyrlæger og landmænd var påvirket af deres sociale miljø, enten i form af et opfattet pres om at udskrive antibiotika eller som en inspiration for deres egne antibiotikavalg.

Resultaterne af denne afhandling peger på, at arbejdet med at ændre antibiotikaanvendelsen inden for sundhedsrådgivningsarbejdet i danske kvægbesætninger skal fokusere på at afsætte tid til dialog og refleksion omkring rationelt antibiotikabrug og antibiotikaresistens. Dette er afgørende for at opnå en forståelse af hinandens perspektiver herom samt for muligheden for at påvirke disse. Gennem forståelse af eksempelvis antibiotikaresistens kan en motivation opnås for at ændre de nuværende procedurer for anvendelse af antibiotika. Er motivationen for forandring på plads, kan muligheden for at planlægge og udføre ændringer af brugen af antibiotika på den specifikke besætning opstå. Staldskoler udgør en mulighed for at skabe rammerne for en sådan reflekterende proces, der potentielt kan lede til forandringsskabende handlinger. Dette er tidligere vist for danske økologiske kvægbesætninger, og nu med denne afhandling også for danske konventionelle malkekvægsbesætninger. Ingen af besætningerne, der deltog i staldskolen i forbindelse med denne afhandlings arbejde, opnåede reduktion eller målbar ændring af antibiotikaforbruget inden for studieperioden. Der blev dog registreret holdningsændringer i forhold til brug af antibiotika blandt de deltagende landmænd, der potentielt kunne medføre reduktion eller ændret brug af antibiotika efter studieperioden. For at opnå reduktion af antibiotikabrug og bedst muligt udbytte i en staldskole foreslås det, at et specifikt antibiotika-relateret reduktionsmål fastsættes i gruppen, og at faciliteringen af gruppen imødekommer alle deltagernes behov videst muligt, herunder deltagernes forskellige forudsætninger og temperament.

Den kvantitative evaluering af antibiotikaforbruget viste sig at være et centralt aspekt i arbejdet med at ændre antibiotikaanvendelsen i sundhedsrådgivningsarbejdet inden for kvægbesætninger. Ved at måle ændringer i forbrug kan det konkluderes, hvorvidt en reduktion eller optimering af forbrug er opnået. Det blev vist, at "state space" modeller kan bruges til at evaluere ændringer i antibiotikaforbrug inden for besætningen, men selve anvendelsen af modellerne skal overvejes nøje og kombineres med indsamling af kvalitative data. Hvis eksempelvis mange ændringer pågår samtidigt i en besætning, bør evalueringen stoppes og gentages under roligere besætningsforhold.

Denne afhandling adresserer forandring af antibiotikaforbrug inden for sundhedsrådgivnings-samarbejdet i danske kvægbesætninger fra flere perspektiver. Først og fremmest fra et lokalt perspektiv, hvor barrierer og påvirkende faktorer for at ændre antibiotikaanvendelsen fra både landmænds og dyrlægers perspektiv identificeres. Afhandlingen diskuterer betydningen af disse faktorer og måder hvorpå viden om dem kan anvendes aktivt til at initiere forandringer i antibiotikaanvendelsen inden for rådgivningsarbejdet. Ydermere præsenteres og diskuteres værktøjer til at monitorere og teste interventioner fokuseret på antibiotikaforbrug. Ud over det lokale perspektiv, diskuteres et strukturelt perspektiv også. Dette indebærer blandt andet en diskussion af påvirkningen fra eksterne faktorer, eksempelvis lovgivning og uddannelse, og deres indflydelse på arbejdet med at forandre antibiotikaanvendelsen inden for sundhedsrådgivnings-arbejdet. Resultaterne kan bruges af relevante aktører og interessenter inden for antibiotika-området, herunder landmænd og landbrugsorganisationer, dyrlæger og myndigheder inden for veterinærområdet under danske forhold. Fordi den danske kontekst beskrives detaljeret i denne afhandling, kan resultaterne også ekstrapoleres til en international kontekst med lignende forhold.

List of abbreviations and terms

ADD	animal daily doses
AMR	antimicrobial resistance
AMS	automatic milking system
AMU	antimicrobial use
DCD	Danish cattle database
DGLM	dynamic generalised linear model
DIM	days in milk
DLM	dynamic linear model
DMS	dairy management system
ECM	energy-corrected milk
HHM	herd health management
HPCIA	high priority critically important antimicrobials
SCC	somatic cell count
VetStat	the Danish veterinary medicines statistics programme
VHHC	veterinary herd health consultancy

1 Introduction

1.1 Background

Antimicrobials are critical for treating bacterial infections in both humans and animals. However, the use of antimicrobials poses a risk when it comes to the development of antimicrobial resistance (AMR) (Chantziaras et al., 2014), meaning that certain microorganisms may become resistant towards certain types of antimicrobials over time. Resistant bacteria or resistant genes caused by antimicrobial use (AMU) in animals may potentially transfer to humans, yet the exact impact and extent of this cross-species transmission is still unknown (Tang et al., 2017). The mere indication of a resistance transfer risk, as well as the risk that AMR poses to animal health and welfare justifies the focus on and need for rational AMU for animals, which can be understood as a refined or reduced use of antimicrobials, as emphasised by the World Organization for Animal Health (2016) and the World Health Organization (2015).

For dairy cattle, the primary actors for promoting rational AMU are farmers and veterinarians. In many countries, veterinarians prescribe antimicrobials and make decisions on when an animal should or should not be treated, while farmers make the decision to call for veterinary assistance in the first place. Furthermore, in some countries, farmers may also make decisions about when and how to treat their animals independently of their veterinarian. Therefore, farmers and veterinarians are the primary responsible actors for refining or reducing AMU within dairy cattle. Their collaborative framework of veterinary herd health consultancy (VHHC) comprises an obvious setting to explicitly work towards this task. A change in AMU behaviour can be promoted where necessary within the VHHC setting.

Research shows that changing AMU is a complex issue for the individual farmer or veterinarian, involving many influential barriers and motivators (Speksnijder et al., 2015a; McDougall et al., 2017; Golding et al., 2019). Identifying these factors and what in particular can influence veterinarians and farmers within a specific context remains an important task in achieving rational AMU (Bokma et al., 2018). Furthermore, understanding what may be acting as a barrier for change for the other party within the VHHC collaboration – and how to overcome such barriers – is crucial for AMU reduction or refinement.

This thesis therefore aims to identify and clarify the factors that influence farmers' and veterinarians' AMU, both from a national and international perspective. Qualitative interview techniques provide a useful tool for identifying barriers for change within the VHHC and for understanding the perspectives and practices related to AMU for both farmers and veterinarians. For that reason, semi-structured interviews form an important basis for the analyses carried out in this thesis.

Once barriers to change and ways to overcome these have been identified, the next goal involves action to make real changes to AMU, and potential interventions to change AMU within dairy farming have previously been investigated. This includes, for example, participatory approaches where farmers, veterinarians, researchers and industry partners meet to discuss action plans to achieve rational AMU (van Dijk et al., 2017), study groups for veterinarians (Pucken et al., 2019), intensified and structured animal health planning at dairy farms (Kuipers et al., 2015; Speksnijder et al., 2017; van den Borne et al., 2017; Stevens et al., 2019) and AMU education for farmers (Turner et al., 2018). Furthermore, benchmarking of AMU among farmers has been used as a tool to promote change (Kuipers et al., 2015), and the use of Stable Schools to allow farmer-to-farmer experience sharing was found to be a successful approach to changing AMU at organic dairy farms (Vaarst et al., 2007). This thesis further investigates the potential for Stable Schools to instigate change in AMU without compromising animal health and production at Danish conventional dairy farms.

In order to ascertain whether the actions related to AMU (e.g. participation in a Stable School or other farm interventions), lead to an actual refinement or reduction in AMU, we need valid quantitative methods that can measure the development in AMU over time. There have been various different approaches to this, for example collecting waste bins of used drug containers (Nobrega et al., 2017; Rees et al., 2021), analysis of treatment records (Menéndez González et al., 2010; Nobrega et al., 2017) or veterinary prescription records (Krogh et al., 2020; Morgans et al., 2021) and conducting questionnaires on AMU (Zwald et al., 2004). Furthermore, some studies have collectively measured farm health, production and treatment records as a proxy for AMU to make sure that farm health and production were not compromised in relation to changes in AMU (Bennedsgaard et al., 2010; Ivemeyer et al., 2011). This thesis therefore builds on previous experience of simultaneously measuring farm health, production and treatment records as a proxy for AMU.

In general, methods for measuring farm AMU should preferably be able to account for the complex farm setting where many varying factors might influence the AMU concurrently, for example there might be periods when a relatively high number of old cows that may be more prone to disease are present at the farm. Taking these factors into account can provide more information about what might have caused the measured change in AMU. Furthermore, the methods should deliver relatively fast answers on the direction of AMU change following an action/intervention, so that the intervention can be halted if there is an undesirable effect. State space models have proven useful in accommodating these criteria (Bono et al., 2013, 2014; Stygar et al., 2017), and this quantitative method for evaluating effect is therefore investigated further in this thesis.

To gain an in-depth knowledge about the complex farm setting, it might be necessary to collect qualitative data at the same time as the quantitative data (Enevoldsen, 1993; Krogh, 2012). This could result in clearer identification of the causes of AMU change, including psychological factors such as changes in values or attitudes. Therefore, this thesis uses a mixed methods approach (i.e. mixing qualitative and quantitative research methods) to investigate and measure changes in treatment risk, health and production on farms following participation in a Stable School.

1.2 Aim and objectives

The overall aim of this PhD project was to investigate the potential to change attitudes and actions related to AMU in dairy cattle production within the context of Danish VHHC.

The overall aim was addressed through the following objectives:

1) Review the internationally identified factors of relevance in terms of achieving rational AMU within the VHHC context in dairy cattle herds.

2) Describe and analyse perceptions and practices related to AMU among Danish cattle farmers and veterinarians.

3) Investigate changes in herd AMU, health and production during an advisory-based intervention from a longitudinal qualitative and quantitative perspective.

4) Demonstrate the use of dynamic quantitative methods for monitoring and evaluating the effect of advisory-based interventions on herd AMU, health and production.

1.3 Outline of the thesis

This thesis is based on five manuscripts and has the following structure:

Chapter 2 presents the study context of the thesis.

Chapter 3 gives an outline of the materials and methods used for the different study sections of the thesis. Figure 1.1 shows the connection between research objectives, study sections and written manuscripts.

Chapter 4 presents the results of the five manuscripts and some additional results not published elsewhere. The results are presented in accordance with the objectives of the thesis.

Chapter 5 is a discussion of the findings of the five manuscripts in relation to the overall aim of the thesis and research conducted within the field.

Conclusions and further perspectives are presented in **Chapter 6** and **Chapter 7**.

Chapter 8 includes the references.

The five manuscripts are presented in **Chapter 9**:

Manuscript I: Veterinary herd health consultancy and antimicrobial use in dairy herds

Manuscript II: The antimicrobial landscape as outlined by Danish dairy farmers

Manuscript III: Danish cattle veterinarians' perspectives on antimicrobial use: contextual and individual influencing factors

Manuscript IV: A mixed methods approach to monitoring changes at Danish dairy farms during a veterinarian-facilitated Stable School to improve health and antimicrobial use.

Manuscript V: Using state space models to monitor and estimate the effect of interventions on treatment risk and milk yield in Danish conventional dairy farms

An appendix containing supplemental files can be found in **Chapter 10**.

The thesis and Manuscript I were written in British English, whereas Manuscripts II-V were written in American English. The variety of English was chosen according to the guidelines of the journals to which the manuscripts were submitted.

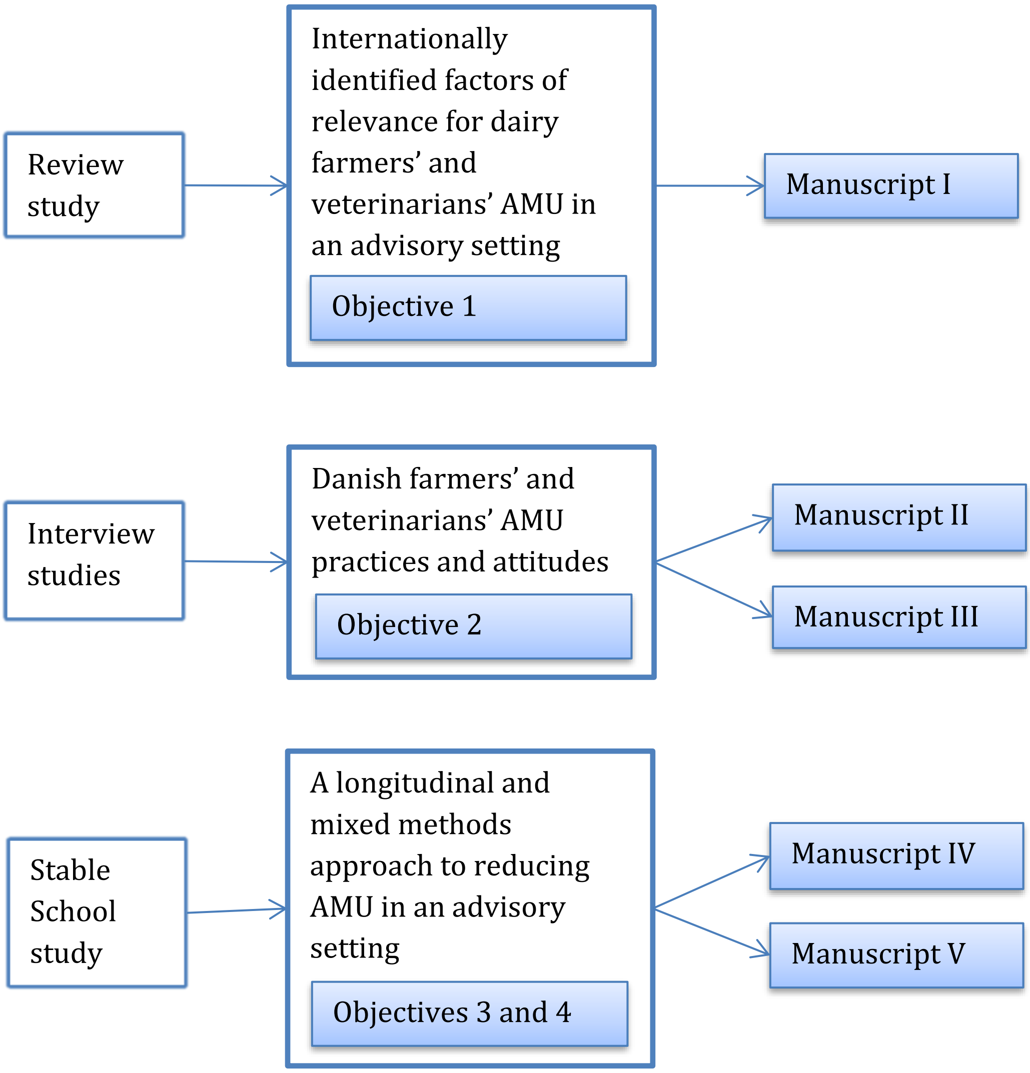

Figure 1.1 Overview of the PhD project, including study sections, objectives, and manuscripts.

2 Study context

This section provides an overview of developments in Danish AMU within dairy farming over time, with reference to the surveillance and legislative measures that remain a central part of the Danish approach to AMU reduction. This is followed by a description of the research framework around this thesis. To conclude, definitions of central terms used in this thesis are given.

2.1 Legislative measures to reduce antimicrobial use under Danish conditions

Over the past 30 years, several measures have been taken to promote rational AMU in cattle in Denmark. According to Danish law, the prophylactic use of antimicrobials in cattle is not permitted (Ministry of Food Agriculture and Fisheries of Denmark, 2021a), and since 1995, veterinarians have only been able to take a 5-10% profit from antimicrobial sales (The Danish Veterinary and Food Administration, 2016; Murphy et al., 2017). In 1995, the health authorities and food authorities established the Danish Integrated Antimicrobial Resistance Monitoring and Research Programme (DANMAP), a surveillance programme covering the overall prescription of antibiotics and the development of resistance in both animals and humans. The use of growth promotors was voluntarily halted by agricultural organisations in 2000 due in part to the data made public through DANMAP (Ministry of Interior and Health and Ministry of Food Agriculture and Fisheries, 2010).

In 2000, a national register on the prescription of medicines within the veterinary field (VetStat) was established with the aim of reducing and rationalising AMU. Data on prescribed drugs are recorded at veterinary level and linked to specific national herd numbers (CHRNR) (Stege et al., 2003; Dupont, 2016). Based on these data, every veterinarian working with cattle and pigs is controlled and supervised by the Veterinary Task Force, established in 2003 by the Danish Veterinary and Food Administration (Ministry of Interior and Health and Ministry of Food Agriculture and Fisheries, 2010).

In 2006, an agreement was made with the industry to liberalise the use of medicines so that farmers were allowed greater access to medicines to treat their own animals. In 2010, this was followed by the introduction of the mandatory Veterinary Advisory Service Contracts (VASC). VASC established a new framework for the collaboration between the veterinarian and the farmer with the aim of preventing disease on farms and rationalising AMU. The framework of the collaboration in terms of frequency and content of visits is described in national legislation and has been revised several times (Ministry of Food Agriculture and Fisheries of Denmark, 2021b).

In 2007, treatment guidelines for cattle practitioners were developed to assist in the proper choice of antimicrobials (Ministry of Interior and Health and Ministry of Food Agriculture and Fisheries, 2010; Murphy et al., 2017). In 2010, the “Yellow Card” initiative was introduced, which set thresholds for AMU in swine and cattle. At the time of writing, sanctions for being above the threshold for cattle producers are limited to an increased number of advisory inspections (Danish Veterinary and Food Administration, 2017).

The cattle sector set a goal of a 20% reduction in the total use of antimicrobials from 2012 to 2018, and in 2014, they requested a limited use of cephalosporins (Danish Agriculture and Food Council), which WHO listed as "Critically Important Antimicrobials". This was followed by a full ban on the use of cephalosporins by 1st September 2019 (Danish Agriculture and Food Council, 2019). New Danish legislation on the use of antimicrobials for the treatment of mastitis in dairy cattle was introduced in 2021. As a consequence, only simple penicillin can be used to treat mastitis if no resistance testing is carried out (Ministry of Food Agriculture and Fisheries of Denmark, 2021b).

2.1.1 Conditions specific to the Danish organic dairy production

Commercial Danish milk production consists of two different production types: conventional and organic, representing two different approaches to promoting rational AMU. Organic dairy production in Denmark has taken further measures to promote rational (and low) AMU on top of the national measures, and the position of organic producers is unique and important when trying to understand the Danish context of AMU.

Denmark has the highest share of organic food sold in the world (Ministry of Food Agriculture and Fisheries, 2015), and about 12% of the milk produced is sold as organic. National milk prices vary between conventional and organic milk. In October 2021, the largest Danish dairy company "Arla" set a price of 2.69 DKK per kg of milk sold as conventional and 3.29 DKK per kg of milk sold to the dairy as organic (Kold, 2021), corresponding to 0.36 and 0.44 Euros per kg of milk, respectively.

Besides a higher income from milk prices, organic dairy farmers are subject to additional regulations in terms of animal welfare, environmental issues and AMU. For example, withdrawal times following antimicrobial treatments are double those for conventional cows. Cows treated more than three times in a year are excluded from organic production. Furthermore, the veterinarian must go to the farm to diagnose and treat all sick animals, except for those younger than 6 months, in which case the farmer may finalise the treatment initiated by the veterinarian (ECC, 1991; The Danish Agricultural Agency, 2020).

In January 2020, the Danish Dairy Board, Danish Agriculture & Food Council and Organic Denmark published new recommendations for organic cattle production. In April 2020, most Danish dairy companies had chosen to follow the recommendations, including limiting the use of broad-spectrum antimicrobials. Only simple penicillin can be used for mastitis, while it must also be the first drug of choice for other diseases. If this has no effect, broad-spectrum antimicrobials can be used, but this must be justified in writing in the log book on the farm (Organic Denmark et al., 2020). These restrictions on the use of broad-spectrum antimicrobials for mastitis were thus in place in the organic sector 1.5 years before their introduction in national legislation.

The requirement that a veterinarian must be called out for every treatment of a diseased animal, combined with the doubled withdrawal time implies different treatment thresholds for organic farms compared to conventional farms. Furthermore, the differences in permitted AMU could also result in a difference in motivation for achieving rational AMU in organic compared to conventional farms. A difference in AMU among conventional and organic dairy herds was found in a study by Krogh et al. (2020). They found that AMU measured in Animal Daily Doses (ADD) was two to three times higher in conventional herds compared to organic herds.

2.1.2 Current status of antimicrobial use and reduction

The historic development described above shows that the Danish measures for promoting rational AMU in cattle have mainly been characterised by national regulation, initiatives driven by the cattle sector, or through the farmer-veterinarian collaboration in the VHHC (specifically referred to as VASC in Denmark). Denmark is a small country and most dairy farmers are organised under one common association. This may potentially ease adaptation to new national initiatives and regulations, which may partly explain the relatively low-level sales of AMU (measured in kg of active compound and population-adjusted) in Denmark compared to many other European countries (European Medicines Agency, 2021). However, despite the extensive regulatory measures, no further reduction in the overall consumption of antimicrobials in cattle in Denmark has been seen over the past 5 years. Data presented in DANMAP showed that AMU in cattle accounted for around 13% of the total AMU in animals in 2020. The overall use of systemic treatment for adult cattle has been decreasing over the last decade, but the AMU in calves and young stock (<1 year) has increased over the same period (Attauabi et al., 2021). Furthermore, there is a large variation in AMU among dairy herds, e.g. a treatment incidence from 0 to 1.47 ADD/100 animals/day among adult cattle at a selection of dairy farms in 2018 (Krogh et al., 2018, 2020). This stagnation in AMU reduction and the large variety in AMU among herds implies that there is room for further reduction.

2.1.3 Current status of antimicrobial resistance in Danish dairy cattle

In Denmark, routine surveillance of resistance in bacteria pathogenic to animals only applies to pathogenic bacteria of zoonotic concern, including *Campylobacter* and *Salmonella*, of which, *Campylobacter* comprises the biggest zoonotic risk from a cattle perspective (Anonymous, 2017). However, resistance levels in *Campylobacter* isolates from cattle meat are generally much lower compared to isolates from broiler meat and broiler and human cases of campylobacteriosis (Korsgaard et al., 2020). Only 24 human cases of *Salmonella* Dublin infection were identified and tested for resistance in 2019, of which, 21 were fully sensitive (Korsgaard et al., 2020). Approximately 10% of Danish herds are currently infected with *Salmonella* Dublin (Anonymous, 2020) and AMR does not seem to be a concern based on the *Salmonella* Dublin strains detected in Danish cattle. Another important zoonotic pathogenic bacteria in Denmark is methicillin-resistant *Staphylococcus aureus* (MRSA), yet only 2% of the 131 sampled cattle herds were found to be positive in a survey from 2019 (Korsgaard et al., 2020).

In terms of resistance among pathogens relevant to cattle diseases, no routine surveillance exists, apart from non-reported surveillance of beta-lactam resistance in national bulk tank milk samples collected twice a year in connection with a *Streptococcus agalactiae* surveillance programme (Pedersen et al., 2017). In 2016, all clinical mastitis isolates sent for investigation to the National Veterinary Institute at the Technical University of Denmark were tested for antibacterial susceptibility. They concluded that resistance levels were low and that multiresistance was rare (Chehabi et al., 2019). The same exercise was repeated for clinical mastitis isolates from 2018 and 2019. The results showed increased resistance towards several classes of antimicrobials among some *Streptococcus uberis* isolates, and increased resistance towards tetracycline among some *Streptococcus dysgalactiae* isolates, while the resistance levels were otherwise generally low (Korsgaard et al., 2020). This generally low resistance level among Danish mastitis pathogens was supported by another study comparing 93 Danish *Staphylococcus aureus* isolates to 85 German isolates, where a lower MIC_{90} was required to inhibit the Danish isolates (Bolte et al., 2020).

As such, the risk posed by the cattle population to human infection with resistant zoonotic bacteria seems to be small. However, the levels of resistance within pathogens that cause disease among cattle – including *Mycoplasma bovis*, which is of increasing concern in international cattle sectors worldwide (Gautier-Bouchardon et al., 2014; Cai et al., 2019; García-Galán et al., 2020) – are largely unknown and have only been investigated to a limited extent.

2.2 Veterinary herd health consultancy

As described in Manuscripts I and III, as well as in Danish legislation (Ministry of Food Agriculture and Fisheries of Denmark, 2021b), the type of VHHC in focus in this thesis is characterised by frequent visits by the same veterinarian, i.e. 4-26 visits per year depending on the type of agreement. The number of visits is correlated with the farmer's authority to treat animals without veterinary intervention (for certain conditions). The veterinarian and the farmer focus on optimising herd health and production, partly through legislatively determined tasks such as a regular evaluation of AMU, animal welfare and biosecurity. The results of these elements are shared at farm visits and in quarterly farm reports, as determined by the legislation. Furthermore, the definition of VHHC given in this thesis assumes access to a large range of farm data on which farm-specific analysis can be conducted. Under Danish conditions, farm-specific data at individual cow level are collected in the national Danish Cattle Database (DCD). As a minimum, farmers are required to register the cows' entry and exit dates, destinations and reasons for movements to and from the herd (i.e. birth, death/euthanasia/slaughter/sale). Furthermore, all treatments must be registered at cow level, either by the farmer or the veterinarian. The DCD collects data from multiple sources. In addition to registrations by farmers and veterinarians, data from e.g. the milk yield recording programme, abattoirs and breeding companies are added to the database (Bundgaard, 2005). Veterinarians have access to the DCD through herd management software and can extract the required data as well as standard and adaptable reports for analysis.

The definition of VHHC used in this thesis is context dependent. However, looking at other countries' VHHC frameworks indicates that this definition might also be valid in many other countries. For example, an approach very similar to the Danish VHHC was established in Finland in 2006, and the same definition of VHHC might therefore apply. This veterinary agreement (called Naseva in Finland) similarly permits farmers to treat certain diseases and is accompanied by a requirement for a certain frequency of veterinary visits depending on the number of animals at the farm (Maa- ja metsätalousministeriö, 2014; European Commission, 2016). A large number of dairy cows in Finland (96.4%) are part of a herd that has this agreement (ETT - Naseva, 2021). The Netherlands has also introduced a legislatively determined VHHC that resembles the Finnish and Danish approach (de Staatssecretaris van Economische Zaken, 2013; Speksnijder et al., 2015b).

However, this definition of VHHC might not be valid in some countries where it is only used to a limited extent despite intensive dairy production. For example, VHHC is voluntary in Germany and only 18.1% of farms in the Southern region, 54.1% in the Northern region and 59.9% in the Eastern region use veterinary advisory services to some extent (Hoedemaker, 2020). Instead, veterinarians mostly treat the diseased animals, and legislation requires them to clinically examine and diagnose them before prescribing medicines (Bundesministerium der Justiz und für Verbraucherschutz, 2018). Sweden has a similar approach to the Danish VHHC. However, it is not required by law and only farmers that fulfil certain herd health criteria can be granted such an agreement. There are fewer allowances in terms of diseases that farmers can treat independently and the type of medicine they may use (Statens jordbruksverk, 2019). Therefore, few dairy farmers choose to establish a VHHC agreement in Sweden (C. Kamaterou, Länsstyrelsen, personal communication, 30 November 2021).

Despite the limited use of VHHC in some countries, the definition of VHHC may still be very similar. For example in the UK, VHHC is voluntary and has only been adopted to a small extent by English veterinarians (Mee, 2007; Ruston et al., 2016). The appropriate form of VHHC and the responsible actors (state veterinarians or private practising veterinarians) have been discussed previously in the UK (Lowe, 2009). However, Green et al. (2012) published a book on "Dairy Herd Health" that introduces a definition of herd health management that harmonises with the definition of VHHC used in this thesis. This definition was: "a method to optimise health, welfare and production in a population of dairy cows through the systematic analysis of relevant data and through regular objective observations of the cows and their environment, such that informed, timely decisions are made to adjust and improve herd management over time" (Green et al., 2012). This definition also fits very well with that given by the Dutch and American authors of Chapter 1 in the book "Herd Health and Production Management in Dairy Practice by Bard et al. (1997). As such, the definition of VHHC used in this thesis might also be relevant to other countries with intensive dairy production, although VHHC might only be used to a limited extent in some of those countries.

2.3 Research framework

The following section will give an introduction to the research findings, theories and methodological approaches in different research fields that form the basis of the work of this thesis.

The history of Danish research approaches to VHHC is especially important for understanding why dynamic quantitative methods and a mixed methods approach to evaluating AMU were used in this thesis. In 1993, Enevoldsen was one of the first under Danish conditions to describe a systematic approach to VHHC that resembles the definition of VHHC used in this thesis (Enevoldsen, 1993). Even then, the importance of qualitative evaluation and critical thinking in the use of quantitative findings was highlighted. For example, knowing farmers' treatment criteria was emphasised as an important prerequisite for a proper evaluation of treatment data. Overall, Enevoldsen advocated approaching VHHC as a dynamic process. This involved setting farmer- and farm-specific goals that should be continuously monitored through key performance indicators. Herd-specific data of sufficiently good quality (e.g. clinical registrations and/or automatically registered production and health data) were the basis for establishing such key performance indicators. These should thus be monitored through appropriate statistical methods, for example graphical tools to reveal temporal variation. The ultimate goal of VHHC was for the veterinarian to provide useful advice about possible solutions when unusual or unwanted patterns were identified in production or health, i.e. to help the farmer make rational decisions. Decisions about what actions should be taken could be further supported by the use of randomised on-farm trials, simulation models or generalised linear models to make causal inferences. It was assumed that farmers were rational thinkers who wanted to make rational changes, i.e. changes that improved production or herd health.

The need for a mixed methods approach to improve the quality of farm-specific analysis was supported and elaborated by Kristensen (2008). For example, without knowing the farmers' motivation, goals or VHHC preferences, the advice given might be misleading. Kristensen found that economic gains were not always an incentive for farmers to change, i.e. good animal welfare and the feeling of being part of a team were also valid motivators. Perspectives on what motivated farmers to change within the VHHC were thus broadened (Kristensen and Jakobsen, 2011).

The importance of taking into account farmers' perspectives within the VHHC was also examined in the work by Andersen (2004). Andersen introduced double-loop learning as a way to integrate farmers' personal values and goals through an open, honest and trusting approach to VHHC in order to give sustainable advice that actually motivated the farmer to act because it aligned with their personal perspectives. In short, double-loop learning implies that the advisor manages to initiate a reflective process within the farmer that leads to action partly because the farmer's personal values and perspectives are included in the process and the advice is therefore perceived as meaningful. In contrast to double-loop learning, no reflective process is initiated with single-loop learning, but potentially half-hearted or automatic action is still taken.

The quantitative methods for measuring herd health performance presented in the work by Enevoldsen (1993) have been further investigated and elaborated in later research to improve veterinarians' opportunities to give qualified, evidence-based and locally relevant advice on how to improve herd health and production within VHHC. Lastein (2012) investigated the use of herd-specific randomised clinical field trials on-farm for generating local evidence-based advice on for example the most effective treatment approach to different diseases. However, she concluded that several human aspects influenced whether the trial was a success, including farmers' and veterinarians' motivation for systematic trialling. As such, it was concluded that trials were only useful in some situations, depending on the type of issue under investigation (whether a clinical trial was a suitable approach), the specific farm setting (whether trialling was possible under practical conditions) and the parties involved (in terms of motivation and consistency in conducting the trial). Krogh (2012) developed a seven-step process for measuring herd health performance within the context of a VHHC. This involved the preliminary use of time series analysis in combination with qualitative exploration to identify unusual herd patterns that required further investigation, i.e. through more advanced data analysis to make causal inferences. As discussed by Krogh (2012), the chosen statistical models should be able to distinguish exceptional variation from random variation, yet this was often not a simple task as farm systems are complex and dynamic and thus difficult to analyse in a simple manner. He proposed the use of state space models to investigate causes of exceptional variation that might refer to specific practices or factors on the farm. State space models have previously been demonstrated as a useful tool to monitor and identify exceptional variation in a variety of production outcomes on dairy farms (Thysen, 1993; Van Bebber et al., 1999; Cornou et al., 2014).

This thesis therefore follows on from years of work within VHHC under Danish conditions that focus on the need for qualitative methods to understand farmer perspectives, values and goals to tailor the VHHC to the farmer. However, this is also combined with quantitative methods in a mixed methods approach to assess data quality, explore exceptional variation in farm data and make causal inference in a way that will be meaningful to the farmer. Furthermore, VHHC research under Danish conditions also emphasises the need for proper quantitative methods, ultimately to give evidence-based, locally relevant and meaningful advice to the farmer. In this regard, the potential of using state space models to measure herd health performance was introduced. This thesis therefore builds on this context-dependent research within VHHC.

Another central development in VHHC research under Danish conditions was the introduction of Stable Schools by Vaarst et al. (2007). In short, a Stable School consists of a small group of farmers participating in facilitated meetings at regular intervals to improve their individual herds. Stable Schools were not thought of as a type of VHHC, rather they were viewed as an alternative to the VHHC of focus in this thesis. In other words, they were seen in opposition to VHHC, which was described as a collaboration between a farmer and veterinarian in an asymmetrical power relationship with top-down knowledge transfer, whereas Stable Schools were based on common learning principles (Vaarst et al., 2007). Stable Schools were found to foster changes in attitudes and practices regarding AMU among participating farmers because they felt that they were in a safe and mutual learning environment with peers who allowed time for reflection. Furthermore, common goalsetting and empowerment through practical advice that had proven to be successful elsewhere was highlighted as initiating change (Vaarst et al., 2007). In 2010, Stable Schools were introduced in Danish legislation as an official alternative to VHHC (Ministry of Food Agriculture and Fisheries of Denmark, 2010). This approach to initiating change through common learning has been an important contributor to research related to VHHC and AMU reduction under Danish conditions and an inspiration for this thesis.

Moving beyond the Danish context, other research related to changes within VHHC has been a theoretical starting point for this thesis. The fact that farmers were motivated by factors other than maximising profits was also introduced by Edwards-Jones (2006), suggesting that a range of non-financial factors can influence farmers' decisions, for example the social context and characteristics of the farmer and farm. In 2010, Jansen et al. (2010b) introduced four types of farmers who veterinarians found difficult to motivate: "proactivists, do-it-yourselfers, reclusive traditionalists and wait-and-see-ers" (Jansen et al., 2010b), named according to their attitudes to external information. They suggested that veterinarians could adjust their communication according to the farmer's preferred uptake of information in order to reach them successfully. Jansen et al. (2010a) also introduced two different communication strategies, i.e. the "central route" of conveying expert advice through e.g. knowledge dissemination, which worked well in cases where farmers were already motivated for change, and a “peripheral route” for cases where farmers lacked motivation. In those cases, the advisor should focus on introducing a small number of simple management changes so that farmers are motivated by their experience of successful steps to practical change (Jansen et al., 2010a).

Both communication strategies, however, focused on rational thinking and expert advice as a prerequisite for change among farmers. In a later paper, authors highlighted farmers’ different mindsets, motivations for change and ways of learning (Lam et al., 2011). They described how farmers are not always rational decision-makers because many aspects influence their motivation and whether they implement a change in actions. For example, motivation might be both externally and internally driven and may interact with the farmer’s mindset, i.e. “what farmers want, know, believe and perceive”, which changes over time and is based on the farmer’s environment (Lam et al., 2011). Therefore, it was proposed that the advising veterinarian take a farmer-centred communication approach by considering the farmer’s individual mindset and identifying his or her current motivation and preferred learning styles. The research by Jansen, Lam and colleagues was based on veterinary advice on udder health. However, they identified similar aspects as relevant in terms of changing behaviour related to AMU, and introduced the RESET model (Rules and regulation, Education and information, Social pressure, Economics, Tools) as an overview of different approaches to instigating a change in AMU behaviour among farmers (Lam et al., 2017).

Much of the previous research on AMU behaviour change within VHHC builds on social cognition models such as the Health Belief Model or the Theory of Planned Behaviour, which concerns influencers of individual behaviour change (Espetvedt et al., 2013; Jones et al., 2015). These models have been further developed to include extrinsic factors influencing individual behaviour change (Ellis-Iversen et al., 2010; Lam et al., 2017; Ritter et al., 2017). However, these models have been criticised for mostly giving an overview of what factors might be barriers or drivers for change, but not how change itself is initiated (Green et al., 2012). Higgins et al., the authors of Chapter 2 of “Dairy Herd Health”, described three phases related to change: going from no intention to an intention to change; actually implementing the change; maintaining the change. In relation to the first phase, they introduced “cold cognition” and “hot cognition” as a description of how intention to change behaviour might come about. “Hot cognition” was defined as automated behaviour not requiring any reflections, whereas taking extra time to enter a reflective process before determining (and potentially changing) the behaviour (in a similar way to the double-loop learning presented by Andersen (2004)) was called “cold cognition” (Green et al., 2012). They highlighted the importance of advising veterinarians to promote an opportunity to reflect and create awareness, potentially also introducing the farmer to other farmers and their practices as an inspiration for change (as in a Stable School). Furthermore, the different communication and learning styles and taking a farmer-specific approach were also highlighted as important for creating an incentive for change (Green et al., 2012). In terms of supporting actual change, Higgins et al. (2012) highlighted the role of the veterinarian in planning and minimising the required effort, making the change a team effort (i.e. including all parties involved at the farm), and empowering the farmer with the necessary tools. Finally, the veterinarian was recognised as being important in maintaining the change through dialogue and follow-up analysis (Green et al., 2012).

Moving beyond the farm and VHHC level, recent research within social sciences and human medicine has emphasised the need to move beyond individual perspectives and actions to fully comprehend the complexity of the AMR crisis and the needed reduction in AMU. As such, it can be argued that additional barriers for change other than lacking communication skills and understanding of the farmer's (and veterinarian's) mindset and motivation might be at play when focusing on AMU behaviour change, e.g. AMR being an abstract risk that can be difficult to fully comprehend (Chandler, 2019; Rynkiewich, 2020). The need to understand how social dynamics and economic and political structures influence the individual farmer's or veterinarian's AMU was therefore highlighted.

All of this previous research on generating change within VHHC (with or without the specific example of AMU) and the need for a contextual understanding of AMU within dairy farming as a prerequisite for change was an inspiration and a starting point for this thesis.

2.4 Definition of central terms

Before moving on to the description of the different study elements of this thesis, the following section provides a short definition of the central terms used. These include: the way "change" was defined and conceptualised throughout the thesis and explicitly used in the analysis in Manuscript IV; the meaning behind "rational AMU"; the choice to use the term "antimicrobials"; how AMU was measured in the quantitative parts of the Stable School study.

2.4.1 Change

Reasons for farmers to change their behaviour have been investigated and described in various ways in previous studies. A recent study by Hayden et al. (2021) included a literature review of these different influencers of change in relation to the expansion of a farming enterprise. They summarised that farmer's goals and attitudes determined the change, i.e. farmers could be driven by a feeling of ownership of an issue, a wish to optimise business, fit within certain social norms, or achieve a greater level of job satisfaction and independence (Hayden et al., 2021). Furthermore, they summarised how farmer socio-demographics, as well as the structure of the farm business and the characteristics of the innovation to be adopted influenced farmers' decision-making in relation to changes (Edwards-Jones, 2006; Hayden et al., 2021).

The definition of change used in this thesis is also presented in Manuscript IV. The definition was inspired by Finstad (1998) and distinguishes between structural and non-structural changes. This thesis investigates changes using different approaches, i.e. qualitative and quantitative research methods alone or in combination. Each method has its strengths in identifying different types of changes. Quantitative methods are appropriate for investigating structural changes, i.e. changes in practices that can be measured or quantified. In contrast, qualitative methods are useful for identifying non-structural changes, i.e. changes in attitudes and perceptions (in addition to structural changes). Asking people questions or observing the way they interact with other people is necessary for identifying these types of changes. When qualitative and quantitative methods are combined, both types of changes can be identified and assessed in parallel, which may lead to new insights.

2.4.2 Rational antimicrobial use and antimicrobial nomenclature

The definition of rational AMU used in this thesis is inspired by the guidelines for the prudent use of antimicrobials in veterinary medicine by the European Commission (European Commission, 2015). Rational AMU first implies reducing the need for antimicrobials by preventing disease, and secondly using antimicrobials only in cases where they are necessary, i.e. refining the use. These cases should be based on clinical diagnoses and diagnostic results if possible, and narrow-spectrum antimicrobials should be prioritised.

Within dairy farming, it is not only antibiotics that are used. Antiparasitic drugs are also widely used, especially for endoparasites such as coccidiosis and cryptosporidiosis (extended list of endoparasites relevant for farms with grassing animals), and for ectoparasites such as flies, and resistance towards antiparasitic drugs is a growing problem (Ihler, 2010; Peña-Espinoza et al., 2016; European Medicines Agency, 2018). The term "antimicrobial" is therefore used in this thesis because this broader definition covers multiple agents that are active against different microorganisms e.g. bacteria and parasites (World Health Organization, 2019). This thesis focuses on a change in attitudes and actions related to any of these types of agents.

2.4.3 Evaluation of antimicrobial use

This thesis will evaluate AMU by looking at developments in the obligatory individual cow treatment records from dairy farms. This evaluation approach reflects farmers' decision patterns in terms of treatment and not the actual amount of antimicrobial used. This type of evaluation was chosen because human decision making and actions surrounding AMU were the primary focus of this thesis, and because these data are available to farmers and veterinarians within a VHHC context. Furthermore, AMU reduction was approached from a dairy production perspective: AMU reduction was only interesting if it did not result in impaired herd health or production. The importance of using treatment records as opposed to the actual AMU in this thesis was highlighted by Krogh et al. (2018), who found that the pattern of human treatment decisions varied from farm to farm, thus complicating the use of the actual AMU as an indicator for herd health status.

There are many other ways to evaluate AMU, depending on the purpose of the evaluation. If the actual AMU at herd level is of interest, the inventory of ADD per 100 animals per day per herd generated by the Danish Veterinary and Food administration and reported in VetStat could be used (Jensen et al., 2004). An example of a graph showing such data can be seen in Figure 4.6 in Section 4.4.1 of this thesis. VetStat shows farm-level data on all medicines prescribed either through veterinary practices or pharmacies on a monthly basis (Stege et al., 2003), and uses that information to calculate the ADD per 100 animals per day for a specific herd. The ADD per 100 animals is antimicrobial class-, species-, indication-, and animal weight-specific (with two standard body weight groups), and Danish summaries of product characteristics (SPC) for treatment length and dosage are used for the estimation (Jensen et al., 2004). A limitation of using ADD per 100 animals is that it reflects the purchasing/stocking pattern and not the pattern of use (Dupont, 2016). The inventories might therefore be misleading since farmers often purchase medicines in batches that could reflect more than a month's worth. However, over longer periods, ADD per 100 animals becomes a more accurate estimate for the overall use of antimicrobials in a specific herd. Another way to measure actual AMU at herd level is to collect medicine waste bins

(Antillón et al., 2020; Rees et al., 2021). This method, however, requires that farmers remember to discard empty packages in the deposited waste bins. Furthermore, it is not possible to know which diseases the antimicrobials were used for, and it is a time-consuming intervention to use in a country where other types of AMU data can be retrieved.

AMU can also be evaluated at a national level, which might allow for comparison between countries if the same type of unit is used. One type of measurement is the overall amount of active compound used (Korsgaard et al., 2020). This measurement (in kg) is used across European countries to compare sales levels, taking into account populations at risk for meaningful comparisons (European Medicines Agency, 2021). This measurement, however, is limited as it does not take the potency of different types of antimicrobials into account (Chauvin et al., 2001). It is also possible to use the defined animal daily dose (DADD) per 1,000 animals per day, as used in DANMAP. DADD is defined for each type of antimicrobial agent in mg of active compound per kg of live animal, as it takes into account the indication, administration route and the species of animal for which the specific drug is appropriate. The DADD may vary from VetStat's ADD per 100 animals per day since different dosage recommendations may be used. Comparisons of AMU among countries is complicated by the fact that not all countries have a national register of veterinary medicine prescriptions or treatment records for individual animals (Craig et al., 2020). Furthermore, there is no global consensus on how to define and measure AMU (Umair et al., 2021).

3 Materials and methods

This section provides an overview of the data and methods used for the different study elements and reflections on how each of the chosen methods contributed to the overall aim and the specific objectives of this PhD project. Detailed descriptions of the individual methods can be found in the respective manuscripts.

Table 3.1 Overview of the individual studies of the thesis divided according to the objectives, with special focus on the study design, data sources, analytical methods and with reference to the specific manuscripts in which the results can be found.

Obj. no.	Objective description and study design	Data sources	Method of analysis	Results presented in
1	Internationally identified factors of relevance for dairy farmers' and veterinarians' AMU[1] in an advisory setting **Study design:** Literature review	**Data:** primary literature on dairy cattle, AMU and intensive production, relevant to VHHC[2] **Search terms:** dairy cattle, antibiotic use, veterinarian, change, advisory service (+ synonyms) **Data sources:** systematic search in seven databases, cited reference search and manual search	Systematic literature review	All details provided in Manuscript I
2	AMU practices and attitudes of Danish farmers and veterinarians **Study design:** Semi-structured interviews	**Participants:** 16 cattle veterinarians and 15 dairy farmers with daily AMU decisions **Recruitment:** purposeful and snowball sampling Recruitment through participant matrix covering age, gender, employment status and type of production used to ensure variation (see Figure 3.2) **Data:** 47 hours of recorded and transcribed interviews	Inspired by the inductive approach in grounded theory Manuscript II: the notion of landscape applied in relation to the analysis	All details provided in Manuscripts II and III Reported using COREQ guidelines[3] The information given to participants can be found in Appendix 1 in Thesis
3	Changes in herd AMU, health and production during a Stable School **Study design:** Longitudinal mixed	**Participants:** six conventional dairy farmers (Herd 1-6) (Herd 4 dropped out) **Recruitment:** purposeful sampling by veterinary practice	**Semi-structured interviews and participant observations:**	All details provided in Manuscript IV and Figure 3.3 in Thesis

	<u>methods case study</u>	**Data:** Individual semi-structured interviews with participants and facilitators in the Stable School: before the start (9.5 hours of recorded and transcribed interviews) and at the end (6.5 hours of recorded interviews) Participant observations: all 11 Stable School meetings **Quantitative data:** same as below (objective 4) but for all herds	Retroductive analysis **State space models for monitoring:** DGLM[4] on <u>treatment risk</u> DLM[5] on <u>milk yield</u>	The information given to participants can be found in Appendix 2 in Thesis
4	Dynamic quantitative methods for monitoring and evaluating the effect of advisory-based interventions on herd AMU, health and production. **Study design:** <u>Longitudinal retrospective effect estimation and monitoring case study</u>	**Participants:** Herd 1 and 6 (now named Herd 1 and 2) **Data:** obligatory registration of individual cow treatments, test day recordings of individual cow milk yield, bulk tank milk recordings (herd level) from the DCD[6] **Outcome variables:** DGLM: Probability of treatment DLM: Daily deviation in milk yield (kg ECM) compared to modelled herd average lactation curve **Risk factors:** Parity and stage of lactation **Interventions:** Herd 1: Teat sealer application (+ shifting to AMS) Herd 2: Adjustment of cubicles	**State space models for monitoring and effect estimation of an intervention:** DGLM on <u>treatment risk</u> DLM on <u>milk yield</u>	All details provided in Manuscript V and Figure 3.3 in Thesis Reported using the STROBE-Vet guidelines[7]

[1]Antimicrobial use. [2]Veterinary herd health consultancy. [3](Booth et al., 2014). [4]Dynamic generalised linear model. [5]Dynamic linear model. [6]Danish cattle database. [7](Sargeant et al., 2016).

3.1 Review study

The first of the three studies in this PhD project was based on a systematic literature review with the aim of understanding the international factors of relevance for VHHC and rational AMU in dairy herds. This first step was important in gaining a thorough knowledge of the scientific field and the methods used from an international perspective, as AMR and reducing AMU is a global concern. Furthermore, it was important for developing the interview guides for the subsequent interview studies and for gaining inspiration for potential advisory interventions to investigate further in the third part of the study (the Stable School study), as these elements had not been decided at this stage of the project. A comprehensive and systematic literature review was therefore conducted. A short description of the methods and materials used in the review study can be found in Table 3.1. A detailed description of the search process was not included in Manuscript I due to space limitations in the journal, and it is therefore presented in the section below. For the remaining information, refer to Manuscript I.

3.1.1 Selection criteria and databases

A thorough search in the Web of Science, PubMed, Ovid Medline, Embase, Scopus, CAB Abstract, and Google Scholar databases was conducted from March to June 2019. A cited reference search was also conducted, combined with a manual search for grey literature. The terms searched were: "dairy cattle", "antibiotic use", "dairy farmer", "veterinarian", "change" and "advisory service", as well as synonyms for all terms. Inclusion criteria were primary literature written in English, studies on dairy cattle and AMU and studies conducted in an intensive production context of relevance to VHHC under Danish conditions.

An overview of the search process can be seen in Figure 3.1. The initial search based on the search terms resulted in 3,703 studies. The titles and abstracts of these studies were screened for relevance according to the inclusion criteria, and a total of 3,504 studies were excluded. Thereafter, the remaining 199 studies were checked for duplicates and 77 studies were removed. A meeting with the co-authors of Manuscript I resulted in the exclusion of another 179 studies. I then read the remaining 43 studies thoroughly, which resulted in 14 exclusions and the addition of 10 studies based on a cited reference search and grey literature. The final number of included studies for the review was therefore 39.

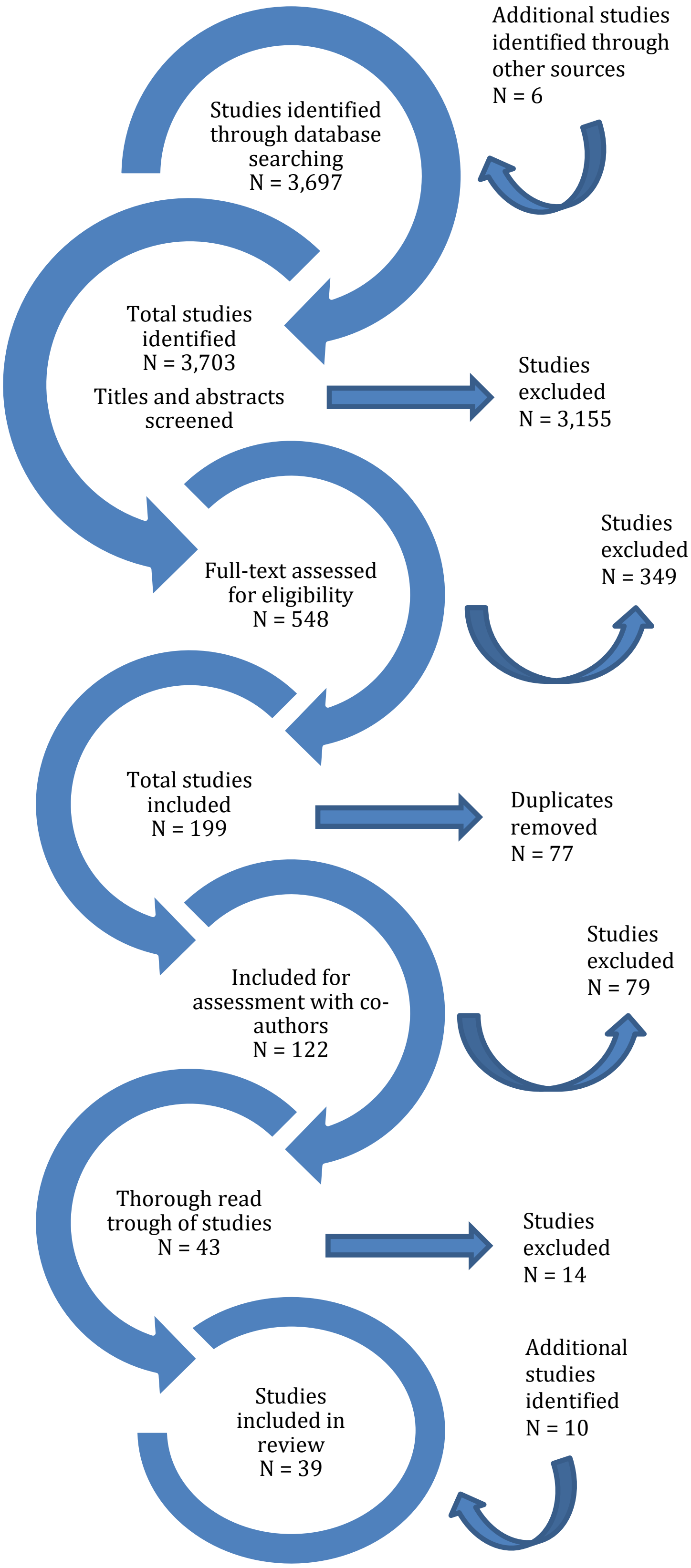

Figure 3.1 Search process of the review study, from top to bottom. The numbers (N=) in the centre of the circles illustrate the total number of studies at that specific point in the process.

3.2 Interview studies

The second study of this PhD project was based on interviews with Danish farmers and veterinarians to investigate their perspectives and practices in relation to AMU in dairy farming. The focus was thereby narrowed from international to national and context-specific perspectives. Qualitative methods with semi-structured interviews were chosen for this study as they allowed an in-depth understanding of the complex issue of AMU. Furthermore, this method allowed new perspectives to arise that the interview guide did not initially cover. A specific focus on veterinarians and farmers was chosen as they comprise the primary actors within the VHHC setting in focus in this PhD project, and investigating each of their perspectives in relation to AMU was considered important for grasping the context-specific barriers to changing AMU and identifying appropriate ways to address these, i.e. specific advisory interventions that could be tested in the last study (Stable School study). This study resulted in two manuscripts: Manuscript II based on farmer interviews and Manuscript III involving the interviews with the veterinarians.

A short description of the participants of the study, how they were recruited and what analytical approach was taken during data analysis can be found in Table 3.1. For detailed descriptions, refer to the manuscripts.

Different elements relating to validity associated with qualitative research methods were considered as part of the interview studies. It is not possible to achieve complete objectivity because as a researcher, I am involved in generating the results. However, there are multiple ways to ensure the results are reliable. As mentioned in the manuscripts and in Table 3.1, Manuscripts II and III were both reported using the COREQ guidelines (Booth et al., 2014). These criteria ensure that the studies cover important elements for valid qualitative research and that results are reported in a transparent way, thus improving the trustworthiness of the studies (Tong et al., 2007). For instance, study validity was considered during the planning phase of the interview studies. A large variation in the recruited participants was necessary to ensure a thick description of the phenomena in focus (Kvale and Brinkmann, 2014), i.e. AMU practices and perspectives among dairy farmers and veterinarians. This was addressed by using a matrix (Figure 3.2) when identifying and recruiting participants. Furthermore, considerations about informational redundancy or data saturation were made both during the process and at the end when the initially planned interviews were conducted (Fusch and Ness, 2015). Before conducting the interviews, I employed reflexive bracketing (declaration of preunderstandings) to further increase the transparency, reliability and objectivity of the study. This helped me to have a non-judgemental and open approach to the interviews and not let my personal suppositions influence the interviews. Member checking was performed during the interviews to make sure I had correctly understood the statements from interviewees, thereby increasing the credibility of the results.

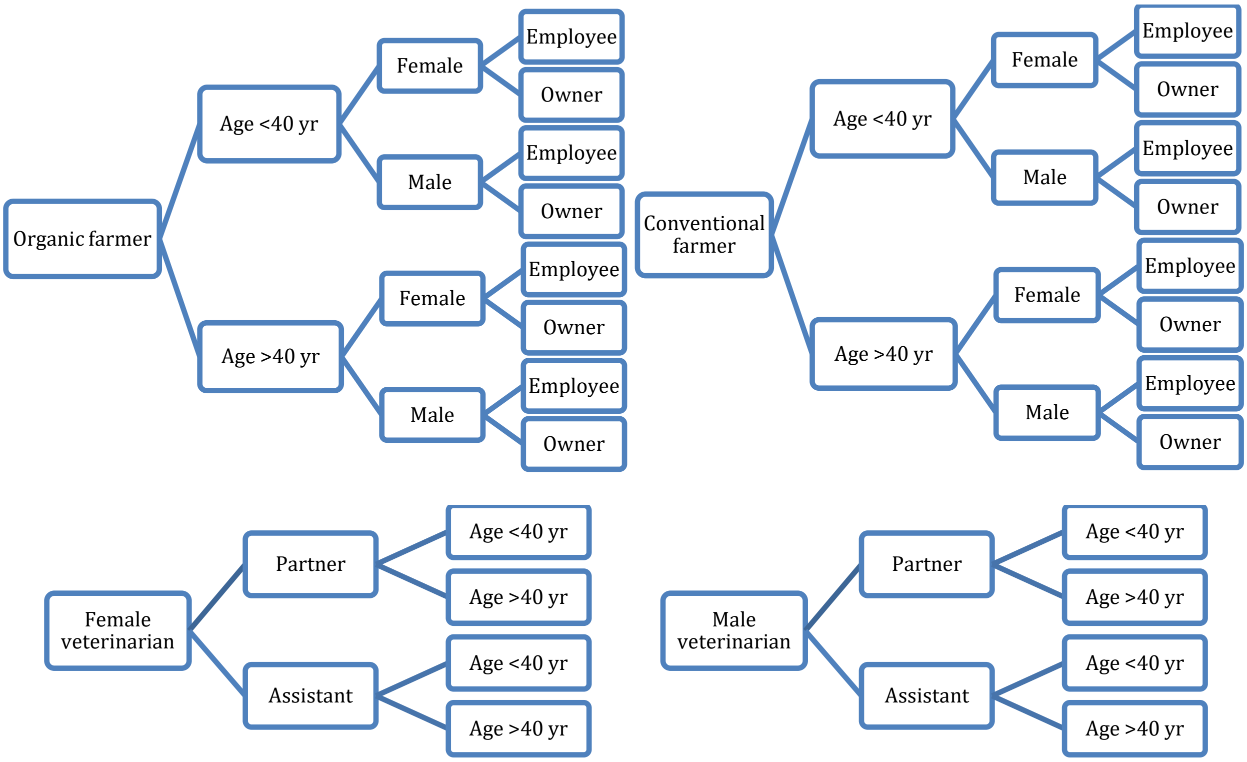

Figure 3.2 Matrices used for participant recruitment. The top two refer to the recruitment of farmers and these included characteristics such as type of production, age, gender and employment status. The bottom two refer to the recruitment of veterinarians and they include characteristics such as gender, employment status and age.

3.3 Stable School study

The third study of this PhD project was a longitudinal retrospective case study using a combination of qualitative and quantitative methods. The objectives covered by this study were: 1) to investigate the potential of the Stable School in instigating changes in AMU, health and production on participating farms using a mixed methods approach; 2) to demonstrate the use of state space models for monitoring and evaluating the effect of Stable-School-related interventions on herd AMU, health and production. This study resulted in two manuscripts: Manuscript IV addressing the first objective of this study, and Manuscript V addressing the second objective.

The initial two studies of the PhD project inspired the choice of Stable Schools as the advisory-based intervention. The literature review identified that previous studies had demonstrated a reduction in AMU after participation in Stable Schools and similar farmer experience-sharing concepts (Bennedsgaard et al., 2010; Ivemeyer et al., 2015; Morgans, 2019), while the interviews highlighted that inspiration from other farmers' AMU practices was important in terms of farmers changing their own practices. Furthermore, Stable Schools represented an opportunity for Danish veterinarians to offer their clients an add on or alternative service to the veterinary agreements already established and required by law (Ministry of Environment and Food of Denmark, 2018). Therefore, it made good sense to investigate the potential of Stable Schools in relation to AMU reduction with reference to the VHHC context of this PhD project.

A combination of qualitative and quantitative methods was chosen because changing AMU is not simply a matter of optimising e.g. management procedures and treatment cut-offs and then quantitatively measuring the achieved reduction in AMU. It is a complex issue that is also influenced by human perceptions, motivation and barriers to change, i.e. reduction might not be achieved if the farm owner does not believe it is necessary, faces more urgent issues that need to be solved before working on AMU, or lacks the employees to facilitate the management optimisations. Therefore, qualitative methods were used in an attempt to gain a thorough understanding of changes (interventions) made at participating farms, including the timing, mechanisms and rationale behind the changes, or potential reasons for not making any changes. This in-depth knowledge of why and when changes were made was useful when analysing the quantitative data; trends in the data, e.g. an increase or decrease in the analysed outcomes for AMU, health and production, could be explained by the qualitative insights on changes made according to the farmer. Furthermore, it could increase confidence that the changes actually caused the trends seen in the data, thereby aiding decisions about which changes appeared to have a beneficial effect, and which changes seemed to have a detrimental effect and should thus be revised or halted. This mixed methods approach furthermore resembles the usual tasks and framework of the VHHC, i.e. in collaboration, farmers and veterinarians might decide on interventions to test at the farm and will therefore need to know the effect of these interventions. As a result, close monitoring from a qualitative (what the farmer did) and quantitative (what effect it had on farm data) perspective often is needed in these advisory situations.

The Stable School study was presented as a case study to focus on demonstrating principles, i.e. the use of the combined methodological approach, using Stable Schools to reduce AMU, conducting interviews and observations to understand the dynamics of reductions, and the use of state space models to monitor and evaluate these reductions. The evaluations were done retrospectively as the state space models were developed during the Stable School and were therefore not available until after the Stable School had finished. This approach was deemed sufficient for demonstration purposes.

3.3.1 Collaboration with the veterinary practice, participants and recruitment

I contacted a local veterinary practice that had already planned to offer Stable Schools to their clients with the overall goal of “improved health – fewer antimicrobials”, following the guidelines described by Lisborg et al. (2005). Two practising veterinarians from the veterinary practice were primarily responsible for recruiting participants among their clients, and planning, organising and facilitating the Stable School included in this study. Of the clients who showed an interest in participating in the Stable School, the practising veterinarians chose a group consisting of six farmers with the aim of creating a homogeneous group with regards to employment status and age. Two meetings were held prior to the start of the Stable School, where alignment of expectations for the Stable School study between the practising veterinarians engaged as facilitators and I was ensured.

No sample size calculations were made prior to conducting the Stable School study, as generalisability was not the purpose of this study. Instead, an in-depth description of the used methods was in focus to demonstrate how a mixed methods approach and the Stable School concept could be applied in VHHC situations. Therefore, sample sizes will not be discussed further and the results of the Stable School study cannot be extrapolated to other dairy herds.

3.3.2 Overview of the Stable School study

As seen in Figure 3.3, Manuscript IV included both qualitative (interviews with participants and observations of Stable School meetings) and quantitative (retrospective monitoring of milk yield and treatment risk for each herd) methods. Furthermore, Manuscript V took a starting point in two of the participating herds (1 and 6) and their herd-specific interventions initiated as part of the Stable School to demonstrate the use of the quantitative methods for estimating the effect of these specific interventions on treatment risk and milk yield. Manuscript V covers all the methodological explanations needed to understand the quantitative elements of the Stable School study, i.e. both the monitoring and effect estimation tool. Each of the methods will be described briefly below, while detailed descriptions can be found in the respective manuscripts.

3.3.3 Qualitative methods

The overall focus of the qualitative investigations was to identify herd-specific changes at the participating herds during the Stable School period. These changes could be both structural (e.g. management changes) and non-structural (e.g. changes in attitudes or beliefs). The methods used to detect these changes included interviews and participant observations in an ethnographic approach as seen in Figure 3.3.

Interviews

Semi-structured interviews were conducted with all participants (farmers and facilitating veterinarians) at the beginning and end of the Stable School period. Only the final interviews were transcribed and these interviews lasted approximately 9.5 hours in total. The remaining non-transcribed interviews from the beginning of the Stable School lasted approximately 6.5 hours, and notes and impressions from these interviews also contributed to the analysis. The choice to transcribe only the final interviews was based on the expectation that participants and facilitators would reflect upon the process as a whole and have a better awareness of what actually made them change (if any change occurred) at the end of the Stable School. After each Stable School meeting, less structured interviews were conducted with the farmer hosting the previous meeting, the farmer hosting the meeting that day, and the facilitating veterinarian. This gave me a better understanding of some of the things that had happened in between the meetings as well as the immediate reactions after a meeting. Since the number of interviewees was restricted to the number of participants in the Stable School, informational redundancy and data saturation were considered differently, i.e. the level of richness of the obtained information was evaluated as part of the analysis process.

Observations

As a second qualitative method, I took an ethnographic approach and observed all Stable School meetings. A complete observer approach (Baker, 2006) was employed for the observations, where I took on a passive role at the meetings, only listening and observing without interacting. This passive role meant that I did not have the chance to ask participants to elaborate on the things they said, and I could only listen to conversations from a distance, sometimes without being able to grasp the full significance of the words said. However, the subsequent interviews allowed me to return to observed elements for in-depth clarification, and the two methods therefore complemented each other well.

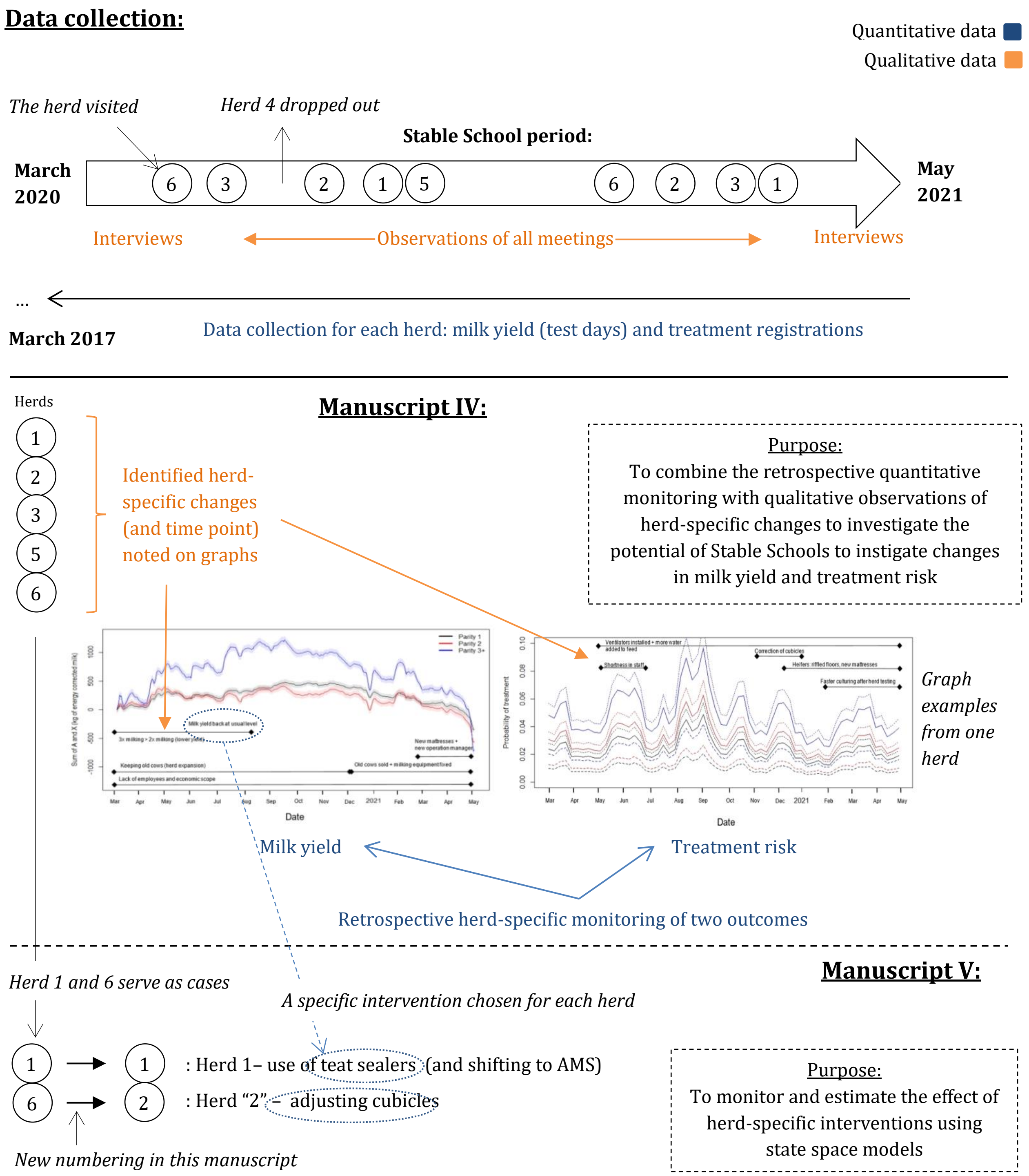

Figure 3.3 Overview of elements in the Stable School study from a methodological perspective. The top part illustrates the data collection for quantitative data, interview data and observations in relation to the Stable School meetings. The middle part illustrates the specific purpose of Manuscript IV, including a

graphical illustration of the mixed methods approach. The last part illustrates the specific purpose of Manuscript V, including the specific interventions that were tested for the two herds.

3.3.4 Quantitative methods: state space models

In terms of the quantitative methods, the overall goal was to identify or develop a tool that would make it possible to monitor changes of specific relevance to the goal of the Stable School (i.e. improved health, fewer antimicrobials) and to select specific changes and test whether they had a significant effect. This tool should ideally be more precise than the decision tools currently available to Danish farmers (e.g. key performance figures), which sometimes have a limited ability to take farm-specific variation and autocorrelation into account, thus giving potentially confounding results. Therefore, I worked with the co-authors of the manuscripts to develop dynamic models that could accommodate the above criteria.

We decided to use milk yield and treatment risk as outcomes; this was a balance of covering the “improved health – fewer antimicrobials” goal of the Stable School while also sticking to a tight schedule. One of the co-authors of Manuscripts IV and V had previous experience of developing dynamic models (Bono et al., 2012, 2013, 2014), including helping to developing a model based on milk yield (Stygar et al., 2017). It therefore made good sense to reuse that model and choose milk yield as the proxy for health and production. The other model needed to measure AMU, which can be done in several ways depending on the data available, as previously outlined in Section 2.4.3. We decided to use the obligatory treatment records registered by veterinarians and farmers and available in the DCD. The modelled probability of treatment therefore represented the farmers’ (and veterinarians’) treatment cut-off, as opposed to actual cow health or the precise amount of antimicrobial used. The reason for choosing treatment records was the availability of these data in a real-life VHHC setting.

The DCD collects herd-specific registrations from different sources, e.g. the farmer, the veterinarian, the dairy company and abattoirs, and in addition to information about individual cow treatment and test day recordings, it also includes cow-level data on birth dates, calving dates, movement dates (culling, slaughter or sale) and dry dates. The first three types of registrations (birth, calving, and movement) are required by law. It is therefore possible to obtain precise information about the number of animals present (and lactating) on a given day in a given herd, as well as their parity and stage of lactation. The DCD is owned by the dairy industry and data validity is ensured in various ways (Bundgaard, 2005).

My task was to oversee the full state space model developing process, making sure the models were in line with the overall goal of the study, contributing with an in-depth understanding of the PhD project as a whole, the limitations that could apply to data originating from cattle herds, and the way a veterinary practice and cattle herds function in terms of data registration. This knowledge helped to make the tools applicable to everyday advisory situations in dairy herds. More specifically, I extracted the data from each of the herds before the final dataset for model building and testing was created in collaboration with the co-authors of Manuscripts IV and V and applied to first the milk yield model and then to the developed treatment risk model. My focus was to understand the practical applicability of the models and interpretation of the results, and not to develop the models independently.

Detailed information on the developed models can be found in Manuscript V. A short description of data used, outcome variables, risk factors and interventions tested can be found in Table 3.1.

3.4 Ethics

The literature review in Manuscript I required no legal permits or ethical approval. Approval from the Research Ethics Committee for Science and Health, University of Copenhagen was obtained for conducting the interview studies in Manuscripts II, III and IV, as well as the participant observations in Manuscript IV (ReF: 504-0066/19-5000). The data from these projects were handled with approval from the Danish Data Protection Agency (Ref. no.: 514-0312/19-3000). For Manuscripts IV and V, all farm owners signed a consent form that allowed the extraction and use of farm data from the DCD. To my knowledge, no farmers withheld treatment for sick animals due to their participation in the Stable School.

4 Results

This section provides a short summary of the results from the five manuscripts in relation to the objectives of the thesis. As such, Section 4.1 summarises results from the review study in Manuscript I on factors influencing AMU within VHHC from an international perspective. Section 4.2 covers two manuscripts, i.e. Manuscripts II and III, and summarises findings from the interview studies with Danish cattle farmers and veterinarians about their perspectives and practices in relation to AMU. This section includes an additional figure (Figure 4.1), which was created to provide an overview of the results from the farmer interviews and has not been published elsewhere. Section 4.3 summarises results from Manuscript IV on the combined qualitative and quantitative approach to evaluating changes in AMU, herd health and production for herds participating in a Stable School. Results from Manuscript V are summarised in Section 4.4, which introduces state space models for monitoring and estimating the effect of interventions made during the Stable School on AMU, herd health and production, and outlines additional results related to the model fit of state space models for monitoring AMU not described elsewhere.

4.1 Objective 1: Internationally identified factors influencing antimicrobial use within veterinary herd health consultancy

In Manuscript I, the review of 39 international research papers from countries with intensive dairy production and VHHC (as previously defined in this thesis) identified a variety of factors influencing the AMU of the two primary actors within VHHC: the veterinarian and the farmer. A socio-ecological model was adapted to provide an overview of the identified extrinsic and intrinsic influencing factors of both actors.

In terms of intrinsic factors, individual attitudes and perceptions of the risk of AMR, responsibility for reducing AMU, and approaches to treatment influenced the AMU choices of veterinarians and farmers. Both parties could engage in “other-blaming”, i.e. directing the responsibility for AMR towards other actors, sectors or countries. Treatment practices could be interwoven with practical experiences and emotions such as frustration at having sick animals, which was primarily identified for farmers, and a professional obligation to ensure animal welfare, as primarily identified for veterinarians.

Furthermore, social norms influenced AMU within the VHHC collaboration. Both veterinarians and farmers were influenced by social contacts in their environment, i.e. peers (colleagues, other farmers) and the farmer/veterinarian in their specific VHHC collaboration. For veterinarians, social influence was specifically described as a pressure to prescribe antimicrobials from colleagues or clients, while for farmers it was primarily described as a willingness to live up to other farmers’ perceptions of “a good farmer”. This was further complicated by the relationship within the VHHC, as the veterinarian might tend to prioritise client retention and building a trusting relationship over choices related to AMU. However, a trusting relationship with an understanding of each other’s goals was emphasised as an important prerequisite for working towards AMU reduction within the VHHC from both a farmer and veterinarian perspective.

A final group of intrinsic influencing factors were related to self-efficacy, i.e. veterinarians' and farmers' ability to reduce AMU was influenced by their individual perception of their capacity to do so. This perception was interwoven with personal experiences related to AMU and emotions such as fear. Seeing other people succeeding in reducing AMU had a positive feedback effect on the individual's self-efficacy.

A range of extrinsic influencing factors related to "Community & Industry", "Culture & Society" and "Knowledge, Skills & Ability" were also mentioned. For example, the medicines and diagnostics available, the industry's potential role in reducing AMU in livestock farming, the framework for VHHC in terms of frequency of visits and prices, as well as legislation on AMU. In addition, different treatment cultures, a lack of knowledge about AMR among both farmers and veterinarians, economic concerns from a business perspective, and the local conditions of the farm were identified as extrinsic influencing factors. These were all valid for both farmers and veterinarians, but their specific perspectives naturally differed. Furthermore, the country in which the study was conducted also influenced specific individual perspectives. Consumer's lack of understanding about dairy farming and the media's portrayal of AMU in agriculture were also identified as extrinsic factors influencing only farmers.

4.2 Objective 2: Perceptions and practices relating to antimicrobial use among Danish dairy farmers and cattle veterinarians

4.2.1 Danish dairy farmers' perceptions and practices

In Manuscript II, interviews with 15 Danish dairy farmers on their perceptions and current practices relating to AMU resulted in a description of the antimicrobial landscape as seen by the dairy farmers themselves. The notion of landscape was used to structure the results of the analysis, and it included landscape structures of local, border and distant relevance to the farmer, as seen in Figure 4.1.

AMR was viewed as a distant element in the daily lives of the interviewed farmers, partly because it is a difficult issue to understand but also because the farmers were of the opinion that other countries and industries had more pressing issues with AMR.

In contrast to the distant threat of AMR, treatment options defined everyday decisions about treatment and constituted an important aspect of the local landscape for all of the interviewed farmers. Decisions about treatment were intertwined with personal attitudes on when to treat, social norms in terms of treatment practices of respected peers, and legislation, i.e. withdrawal times, requirement for veterinary intervention and medicines available for use. Available or applied treatment options therefore differed among the interviewed farmers. At one end of the scale, some farmers focused on preventing disease – an attitude primarily identified among some of the interviewed organic farmers. At the other end of the scale, some farmers perceived disease as something that could be controlled through treatment.

Another important topic in the local farm setting was that the common physical characteristics of feeding and housing conditions were challenged and rethought, especially by some of the interviewed organic farmers. In contrast, other farmers seemed to accept the current farm conditions and used this to justify the current level of AMU.

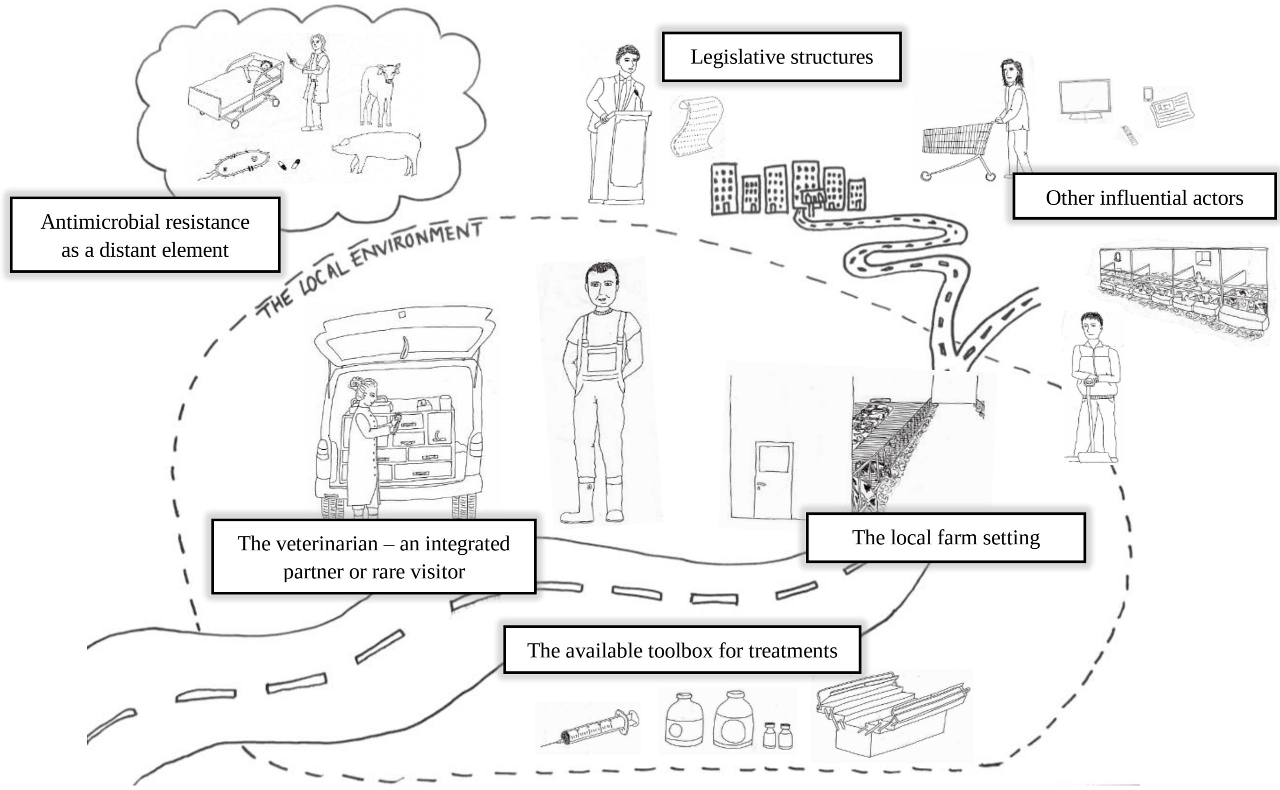

Figure 4.1 The local, border and distant structures of the antimicrobial landscape as outlined by the interviewed Danish dairy farmers. The local structures are positioned close to the farmer within the local environment, while border structures are positioned at the edge of the local environment. The distant structure of antimicrobial resistance is positioned in a cloud far away from the farmer.

The last of the local antimicrobial landscape structures involved the veterinarian and his or her role at the farm. Irrespective of the type of production (conventional or organic), the role of the veterinarian could be decoupled and restricted to only legislatively determined tasks, or the veterinarian could be a close sparring partner. This active role of the veterinarian was often associated with the interviewed farmer's active choice to reduce AMU.

The structures at the border of the antimicrobial landscape included legislation and other influential actors such as consumers, the media, citizens and other farmers. Some differences were identified between the organic and conventional farmers interviewed with regard to their perceptions about legislation. This is likely to be due to clear differences in legislation governing the access to and options for use of antimicrobials between the two production types.

There was a shared frustration among interviewed farmers towards influential actors in relation to the media portrayal of AMU in dairy farming as well as consumer ignorance. However, some organic farmers acknowledged the importance of listening to and accommodating consumer needs. The opinions and practices of other farmers were important to all interviewed farmers – either as inspiration or as a way to differentiate themselves from their peers.

4.2.2 Danish cattle veterinarians' perceptions and practices

In Manuscript III, interviews with 16 Danish cattle veterinarians about their current perspectives and practices in relation to AMU led to the identification of several individual and contextual factors that influenced their AMU through a complex pattern.

The individual factor of personal experience of specific treatment regimes, herd-specific problems or concerns guided the AMU choices of the interviewed veterinarians. Emotions were also intertwined with personal experiences, i.e. experiences of failed treatments could lead to unpleasant feelings such as guilt or anguish from seeing animals die. As a result, some of the interviewed veterinarians prescribed based on personal experiences. Furthermore, the contextual factor of accessible scientific evidence was intertwined with personal experience and prescribing decisions. Some of the interviewed veterinarians believed that there was a dearth of reliable scientific evidence on AMU choices applicable in a local farm environment, and they therefore prescribed based on personal experiences. They requested more treatment effect research and efficient diagnostic tools that could minimise reliance on personal experiences and make diagnosis more objective.

Social relations also influenced the interviewed veterinarians' AMU choices, but in a complex mechanism interwoven with both individual factors such as emotions and contextual factors such as working experience and the business structure within the veterinary practice. For example, less experienced veterinarians struggled to oppose farmers' preferences for certain antimicrobials and colleagues' prescribing choices when they were not in line with their own choices. The fear of losing favour with the farmer, and ultimately the fear of being dismissed from their job drove the less experienced veterinarians to comply with the preferences expressed by surrounding social relations. In addition, the recognition that other veterinary practices would offer any services that they themselves withheld led the interviewed veterinarians to comply with farmers' preferences, irrespective of their level of experience. These social influences made the interviewed veterinarians adopt various communication and persuasive strategies, such as gradually offering their own ideas over time so that their relationship did not become strained. Other interviewed veterinarians were less affected by their social milieu and employed a more confrontational communication style in relation to AMU choices. Commonly, all interviewed veterinarians stressed the importance of establishing trust in their relationship with the farmer in order to shift the farmers' AMU in any direction.

Legislation was a key contextual influencing factor under Danish conditions. For some of the interviewed veterinarians, the supervision by authorities motivated them to change their AMU, and some perceived the current legislative framework as a great help in ensuring good animal welfare and rational AMU at dairy farms as a result of their frequent farm visits. However, many of the interviewed veterinarians also emphasised how legislation and the many predefined activities reduced motivation for both parties within VHHC. Furthermore, veterinarians and farmers have shared responsibility for AMU since the liberalisation of medicines in 2006, which the interviewed veterinarians found challenging. Balancing the conflicting roles of supervising AMU at the farm as well as being a close sparring partner for the farmer was described as being difficult. As a result, the interviewed veterinarians suggested stricter regulations on antimicrobial substances available to farmers. As such, the contextual factor of legislation was intertwined with individual factors such as motivation and responsibility.

The interviewed veterinarians' perception of AMR was another contextual factor that influenced their AMU. The interviewed veterinarians had differing views of how frequently they encountered AMR at their respective farms, but in general, AMR was not something they thought about on a regular basis. Rather, they believed that by adhering to Danish AMU legislation they indirectly mitigated the risk of AMR. Furthermore, some of the interviewed veterinarians believed that other countries needed to reduce their AMU before Denmark should reduce any further. In addition, some of the interviewed veterinarians raised concerns about animal welfare if AMU should be reduced further. As such, the contextual factor of AMR was intertwined with individual factors such as personal experiences of resistance and attitudes towards animal welfare and the need for further reduction.

4.3 Objective 3: A mixed methods approach to evaluate change in antimicrobial use, health and production in herds participating in a Stable School

In Manuscript IV, 14 interviews with the participants and facilitators of a Stable School alongside nine observations of Stable School meetings comprised the qualitative part of a mixed methods approach to investigate changes related to health, production and AMU made in herds participating in a Stable School. The developed treatment risk and milk yield monitoring models for each herd comprised the quantitative part.

In general, participation in the Stable School instigated structural and non-structural changes that related to health, production and AMU. Table 5 in Manuscript IV shows herd-specific examples of these changes. As described by the participants, structural changes were initiated based on advice given by the visiting farmers when it was practical, easy to implement and made good sense to the farmer. Alternatively, they initiated structural changes inspired by the practical procedures observed or discussed during visits to the other participants' farms. In terms of non-structural changes, the participants described that the Stable School provided a safe and confidential environment where opinions and experiences could be shared and attitudes changed without ridicule. Furthermore, the increasing familiarity within the group made some participants feel more self-confident and thus more trusting of their own farming experience.

Some external barriers to change existed, as described by the participants and facilitators. These included farm-related barriers such as a lack of employees and having a stressful time at the farm, as well as barriers related to the way the Stable School was run. These Stable School-related barriers included reflections about the group composition, i.e. enough participants to ensure sufficient benefit from the meetings and yet not so many that the confidential and safe atmosphere within the group was compromised. It was perceived as important that the facilitator aimed to facilitate the group in a balanced and structured way to express commitment to the Stable School and ensure that all participants were heard equally. Clearly presenting the purpose of the Stable School, aligning expectations through common goal-setting within the group and frequent follow-up of these goals through figures and numbers were also highlighted by the farmers as important prerequisites for achieving change at the participating farms.

More specifically, the changes in AMU, health and production at each of the participating herds are summarised Table 4.1. The development in treatment risk as a proxy for AMU, and milk yield as a proxy for herd health and production during the Stable School period for each of the herds (except herd 3) and selected qualitative information of relevance to these two outcomes can be seen in Figure 1-8 in Manuscript IV.

Table 4.1 Changes in probability of treatment and milk yield as well as structural and non-structural changes in Herds 1, 2, 3, 5 and 6 during the Stable School period.

Herd	Structural changes	Non-structural changes	Changes in treatment risk	Changes in milk yield
1	Teat sealers Claw bath routines Robot routines	AMU attitude change Increased confidence	The probability of treatment at the end of the Stable School period was similar to the level at the start of the period, but with a decreasing trend from a peak in June 2020.	The milk yield fluctuated during the period, with parity 1 cows generally performing worse compared to the herd average at the start of the period. In contrast, older cows performed better than the herd average when the Stable School period ended. The milk yield across all parities dropped when milking robots were initiated in October 2020.
2	Start insemination time Bought claw baths	Valued time for reflection	The probability of treatment was stable throughout the whole Stable School period.	The milk yield fluctuated and ended at a lower milk yield level for all parities according to the herd average.
3	Ventilation of calf shed *S. aureus* separation procedures	Received valuable advice to use later	*Not produced.*	*Not produced.*
5	*None*	Reflections on employee handling	The probability of treatment started and ended at approximately the same level, but with fewer fluctuations in the last half of the Stable School period.	Parity 3+ yielded almost 1,000 kg ECM more than the herd average until the end of the Stable School, whereas other parities remained at a more stable level. The milk yield of all parities dropped at the end of the Stable School.
6	Adjusted cubicles	Increased confidence	The probability of treatment started and	The milk yield for all parities was lower than the herd

	More water in feed Installed ventilators	and farming experience	ended at approximately the same level and fluctuated throughout the whole period. During the second half of the period, the fluctuations were less marked.	average during the first half of the period, whereas it was similar to the herd average during the second half of the period.

4.4 Objective 4: State space models to monitor and estimate the effect of interventions on antimicrobial use, health and production at herds participating in a Stable School

In Manuscript V, two of the herds presented in Manuscript IV were selected to demonstrate the use of state space models for estimating the effect of interventions planned during the Stable School on AMU, health and production. In addition, Manuscript V described in detail the state space models for monitoring AMU, health and production, which were also used in Manuscript IV. For that reason, Figures 1, 2, 7 and 8 (covering Herd 1 and Herd 6) in Manuscript IV were reused in Manuscript V as Figures 3, 4, 7 and 8, but in a slightly different context. In Manuscript V, the monitoring graphs were used to gain an overview of the development in milk yield and treatment risk in the two herds before focusing on the period when the specific interventions were implemented.

The intervention investigated further for Herd 1 was the application of teat sealers in August 2020. However, a second "intervention", i.e. the initiation of milking robots in October 1, 2020 was also modelled to be able to differentiate the effects seen from the two interventions occurring in quick succession. The monitoring graphs on treatment risk showed a short peak followed by a decrease in probability of treatment in August 2020, when the application of teat sealers was initiated (Figure 3 in Manuscript V). The monitoring graphs on milk yield showed a peak in milk yield among parity 3+ cows, followed by a decrease for all parities in August 2020 (Figure 4 in Manuscript V).

The intervention effect of teat sealer application was evaluated for udder treatment risk within a four-month period after initiation, as the onset of effect was expected to be around 2 months. A gradual onset was applied for milk yield, i.e. as cows calved after having teat sealers applied. According to Figure 5 in Manuscript V, the application of teat sealers had no statistically significant effect on udder treatment risk. According to Figure 6 in Manuscript V, the application of teat sealers had a statistically significant negative effect on milk yield, i.e. milk production decreased by 6 [95%CI:-0.5;-11] kg ECM per cow per day for cows that had completed a dry period after having teat sealers applied. However, the effect was timely intertwined with the second intervention, i.e. the introduction of AMS.

The adjustment of cubicles for cows in parity 2 and older in November 2020 was the intervention investigated further for Herd 2 (Herd 6 in Manuscript IV). The probability of treatment fluctuated from 1-4% and 1-6% in November and December where the intervention was running (Figure 7 in Manuscript V). The milk yield monitoring graph shows an increasing trend in milk yield for parity 2 and parity 3+ cows in November and for the following 3 months (Figure 8 in Manuscript V).

The intervention effect of adjusting the cubicles was evaluated within a two-month period for both treatment risk and milk yield for cows in parity 2 and above, despite uncertainty over the expected time of onset of effect. This uncertainty was due to the fact that the cubicles were adjusted gradually over time. The adjustment of cubicles had no statistically significant effect on treatment risk for cows in parity 2 and above, as seen in Figure 9 in Manuscript V. According to Figure 10 in Manuscript V, adjusting the cubicles initially had a short statistically negative effect on milk yield for cows in parity 2 and above, followed by no statistically significant effect on milk yield for the rest of the period.

4.4.1 State space model validation

Forecast errors

Validation of the state space models used in Manuscript IV and V has not been presented elsewhere but comprises an important step in knowing whether the model assumptions for the dynamic linear model (DLM) and the DGLM are justified, thus supporting the use of results reported from the developed models. The model assumptions are that the forecast errors are independent and that they follow a known distribution, i.e. a normal distribution for the DLM and a binomial distribution for the DGLM.

The model assumption that the forecast errors follow a known distribution was evaluated by plotting the forecast errors (standardised forecast errors for the DLM), i.e. the difference between the observed and forecasted values over time for both the DLM for milk yield and the DGLM for treatment risk. These plots can be seen in Figure 4.2 and Figure 4.4. Binominal data where small probabilities are expected (as in the DGLM on treatment risk; few treatment registrations are expected) mean that the forecast errors should be skewed in a positive direction. For normally distributed data (as in the DLM on milk yield), approximately 95% of the standardised values should fall between -1.96 and 1.96.

The model assumption that the forecast errors should be independent and thus non-correlated was evaluated by plotting the previous forecast error against the current forecast error as seen in Figure 4.3 and Figure 4.5. For the forecast errors to be non-correlated, most of the points plotted should be symmetrical, i.e. positioned close to a “straight” horizontal line with a mean of zero and with half of the forecast errors on each side.

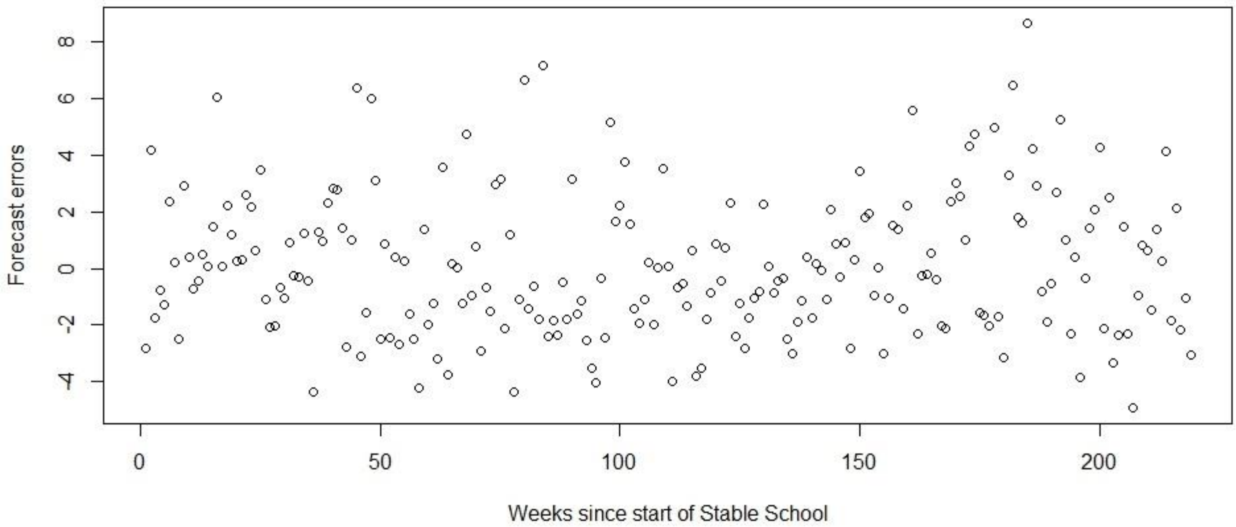

Figure 4.2 Plot showing the difference between the observed and the predicted values, i.e. forecast errors (y-axis), over time for the dynamic generalised linear model on treatment risk. Herd 6 in Manuscript IV (Herd 2 in Manuscript V) is used as an example. The number of weeks since the start of the Stable School for the specific forecast error is plotted on the x-axis.

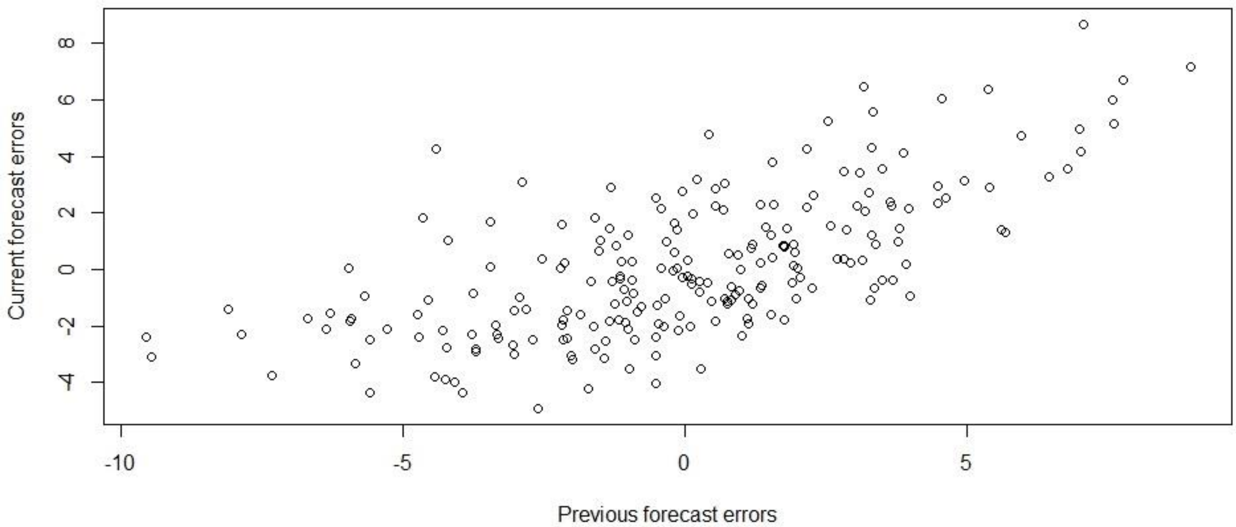

Figure 4.3 Correlation between current forecast errors (y-axis) and previous forecast errors (x-axis) for the dynamic generalised linear model on treatment risk. Herd 6 in Manuscript IV (Herd 2 in Manuscript V) is used as an example, as in Figure 4.2.

The forecast errors for the treatment risk model (Figure 4.2) seemed to be slightly skewed towards the positive side as expected. Furthermore, no critical outliers were observed. Therefore, the assumption that the forecast errors follow a binomial distribution seems to be justified. The correlation structure in Figure 4.3 indicates that our DGLM is not perfect, as the observations are not positioned on a straight horizontal line around zero. This could be due to possible unstable periods for Herd 6 in terms of probability of treatment, meaning that the model sometimes made imprecise predictions about the probability of treatment. Furthermore, it could be due to e.g. the seasonal effect not being modelled directly.

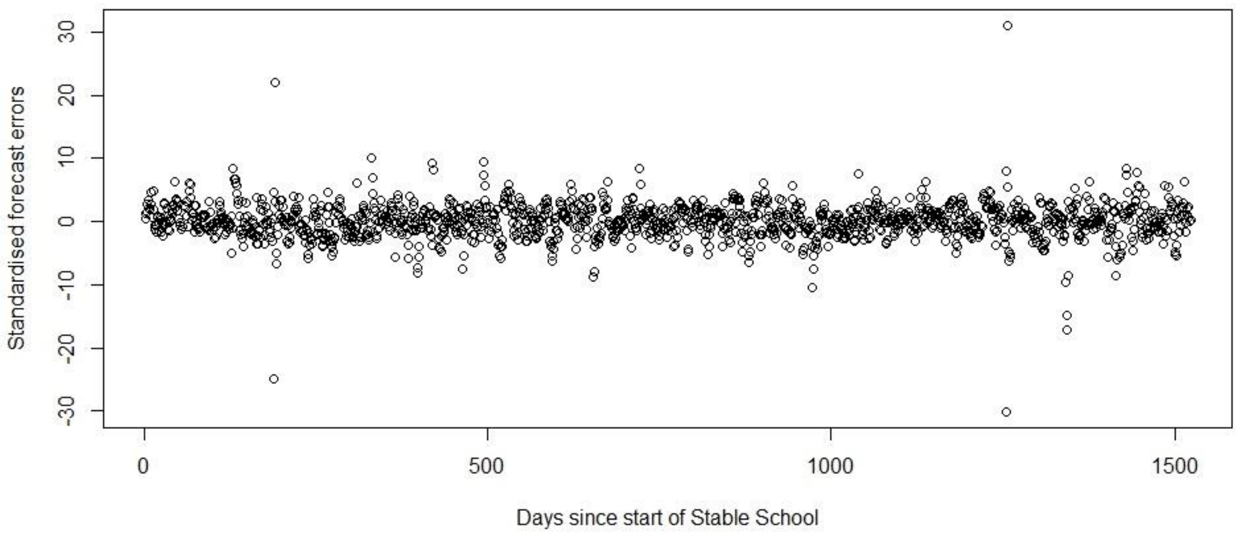

Figure 4.4 Plot showing the difference between the observed and the predicted values, i.e. the standardised forecast errors (y-axis), over time for the dynamic linear model on milk yield. Herd 1 in Manuscripts IV and V is used as an example. The number of days since the start of the Stable School for the specific standardised forecast error is plotted on the x-axis.

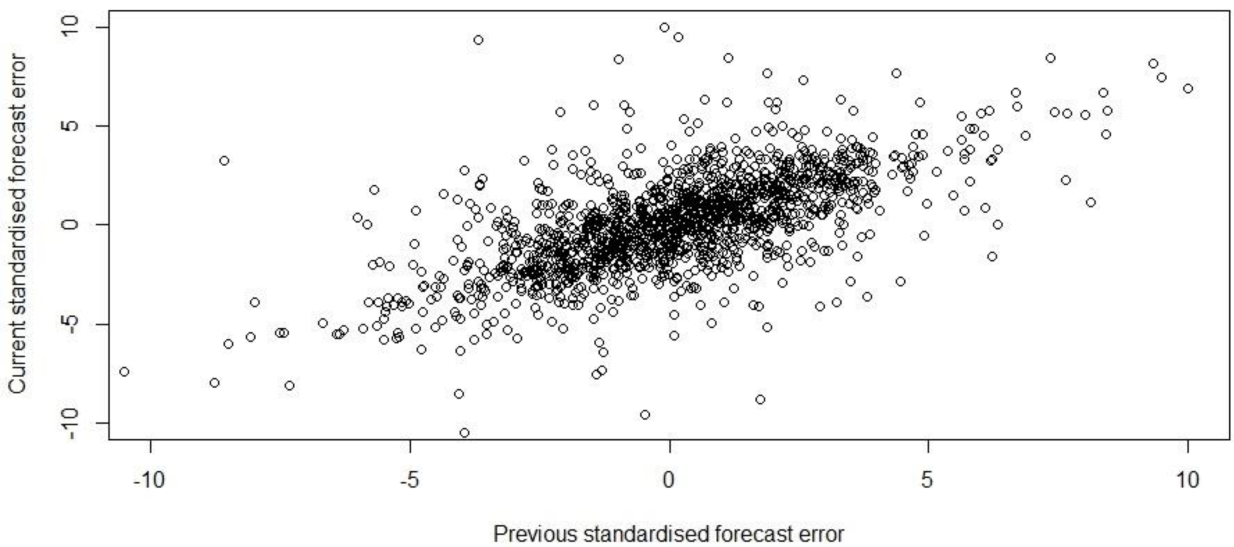

Figure 4.5 Correlation between current forecast errors (y-axis) and previous forecast errors (x-axis) for the dynamic linear model on milk yield. Herd 1 in Manuscripts IV and V is used as an example, as in Figure 4.4.

The standardised forecast errors for the milk yield model in Figure 4.4 were positioned on a rather straight horizontal line around zero, with the exception of a few outliers. These outliers were due to the collection pattern of bulk tank milk in Herd 1. The milk was typically picked up every second day in Herd 1, but there was an unusual collection pattern affecting certain days. Therefore, the moving average that was applied to distribute the daily amount of bulk milk picked up evenly over time resulted in a number of skewed observations. This is also evident from the fact that the outliers on approximately day 200 and day 1,250 fit together pairwise. Being able to explain these outliers justifies the assumption that the forecast errors follow a nominal distribution. In relation to the correlation structure in Figure 4.5, the observations are not positioned on a straight horizontal line around zero, instead the plot is similar to that of the DGLM in Figure 4.3. It is therefore difficult to justify the assumption that the standardised forecast errors are independent. As with the explanation for the DGLM, this could be due to the fact that Herd 1 experienced unstable periods in terms of milk yield. Furthermore, it could be because the seasonal effect was not modelled directly.

Treatment risk monitoring graphs compared to VetStat data

Another way to validate the developed DGLM model on treatment risk was to compare the monitoring graphs with the data available to farmers and veterinarians for monitoring the AMU at dairy herds. As written in Section 2.4.3, there are two main ways to evaluate AMU at herd level under current Danish conditions: 1) through treatment records, as done in this thesis (Manuscripts IV and V) and shown in Figure 4.7, and 2) through data on the farmer's veterinary prescriptions, available through VetStat in ADD per 100 animals per day, as seen in Figure 4.6. The two evaluation methods were compared to ascertain whether using treatment risk as a proxy for AMU was plausible and whether the treatment records assumed to include antimicrobials used in the DGLM seemed to be correctly identified.

The two figures seem to follow the same graphical pattern to a degree, and the treatment records including antimicrobials therefore seem to be correctly identified. In Figure 4.6, a number of peaks not identified in Figure 4.7 can be seen, e.g. in December 2020. This peak is followed by a period where the ADD per 100 animals per day seems to be relatively lower than the estimated probability of treatment during the same period. However, it is important to remember that the ADD per 100 animals per day is calculated based on prescribing patterns and not use patterns, which may explain the deviation in pattern between the two figures. In December 2020, Herd 1 might have been given a prescription for a large amount of antimicrobial that they did not use within a short period of time. Due to these at times inaccurate estimates in terms of ADD per 100 animals per day, the treatment risk monitoring graphs appear to offer a useful alternative for monitoring AMU and related behavioural patterns at herds over time.

Herd 1 was used as an example, but similar tendencies also applied to the other three herds (Herds 2, 5 and 6) in Manuscripts IV and V (not illustrated).

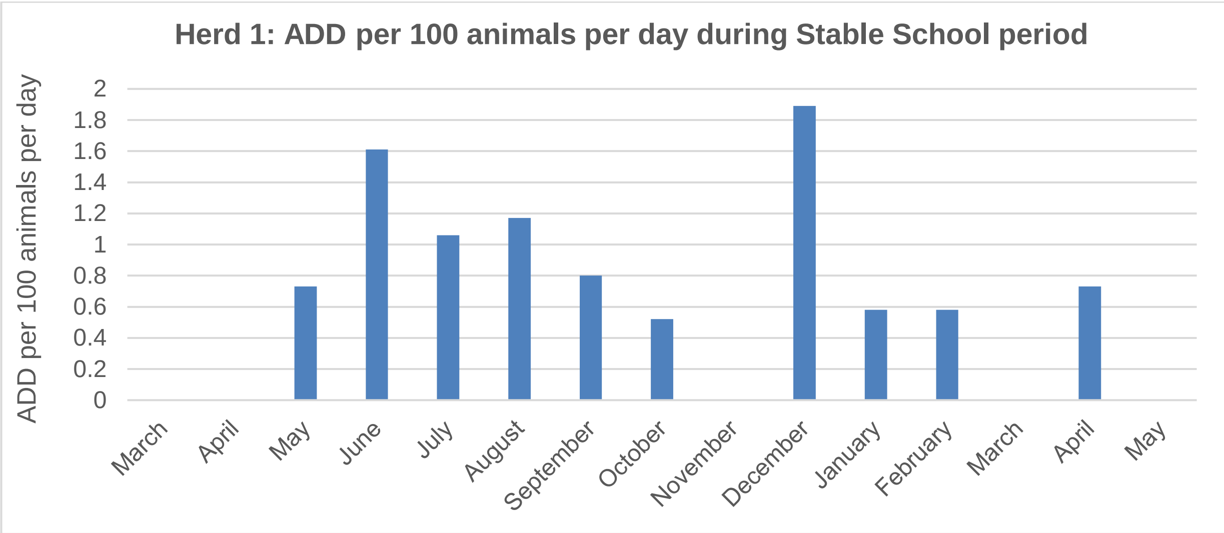

Figure 4.6 The Animal Daily Doses (ADD) per 100 animals per day for Herd 1 for each month during the Stable School period, based on data from VetStat. The monthly ADD per 100 animals per day is calculated as a rolling average over 12 months, taking into account the number of animals in specific age groups present in the herd, the specific antimicrobial classes prescribed and the indication. Standard dosages and treatment durations are used in the calculation.

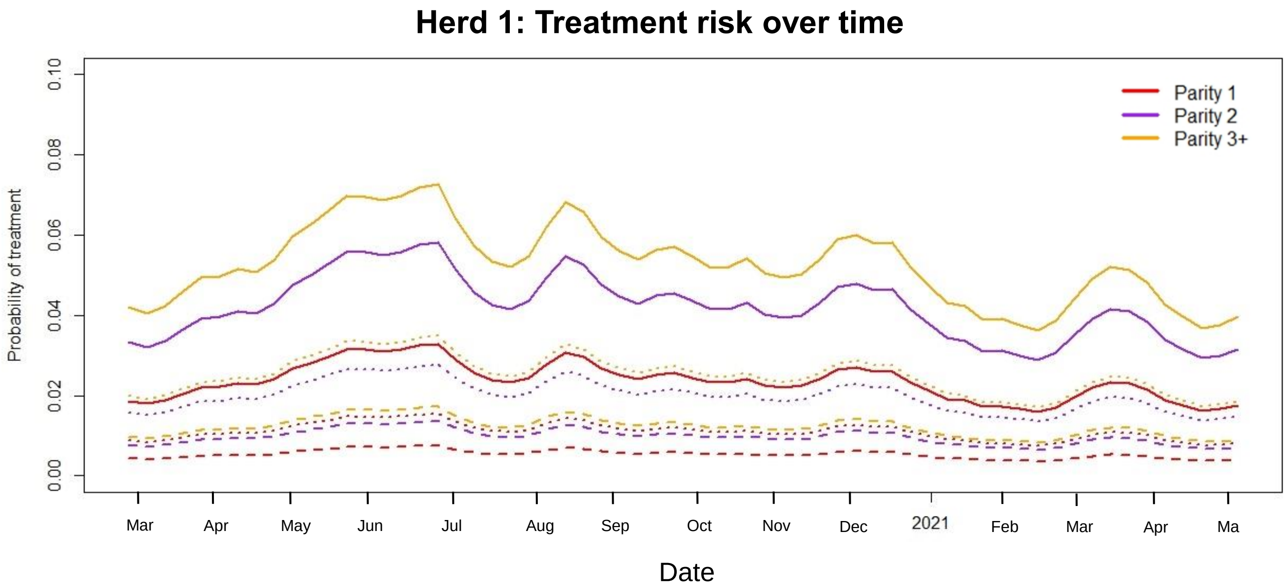

Figure 4.7 Monitoring graph showing the weekly probability of treatment by parity and stage of lactation for Herd 1, reused from Manuscripts IV and V. The solid lines represent cows 0-60 days in milk (DIM), cows 61-280 DIM are represented as stippled lines, and cows ≥ 281 DIM are represented as dotted lines.

5 Discussion

The aim of this PhD project was to investigate the potential for changing attitudes and actions related to AMU in dairy cattle production within the Danish VHHC context. In the following section, selected findings from Manuscripts I-V will be discussed and interpreted in relation to the study context, the overall aim of the thesis, previous research and the additional results included in the thesis.

The focus of the discussion will be on how AMU in dairy cattle production can be changed within the VHHC context, i.e. with a focus on the practical applicability of the results to the relevant parties. The discussion will be conducted at two levels. The first level takes its starting point from the local perspective of the veterinarian and the farmer within the VHHC collaboration and the potential to change AMU within that setting. Within the local setting, appropriate methods to quantitatively measure whether rational AMU has been achieved in dairy herds will also be discussed. Furthermore, the potential to change AMU using Stable Schools as an alternative to more classical VHHC will also be discussed. The second level of the discussion takes its starting point in a structural perspective on how AMU changes can be achieved through VHHC, e.g. in terms of legislation, veterinary education and apprenticeship. In principle, such structural elements are beyond the specific context of VHHC, however, the focus of the discussion is how they may still indirectly influence changes in AMU within the VHHC. The need to focus on several different perspectives when aiming to change AMU was identified in Manuscript I and in recent literature (Chandler, 2019; Broom et al., 2020; Rynkiewich, 2020).

The discussion topics were selected based on their relevance to the overall aim of the thesis. Furthermore, topics that had not already been discussed in detail in the separate manuscripts were chosen. For that reason, I refer to the discussions in Manuscripts I-V for additional aspects relevant to changing AMU within VHHC. In addition, topics where central findings from several manuscripts could be combined were prioritised. An overview of the discussion topics can be seen in the illustration on the front page.

A discussion about the chosen methodologies and the implications thereof, as well as the external validity of the findings of this thesis will follow the general discussion about how AMU can be changed within VHHC.

5.1 Changing antimicrobial use within veterinary herd health consultancy from a local perspective

The first part of the discussion takes a starting point in the local reality of the VHHC and considerations about changing AMU within this setting based on the findings from Manuscripts I-V. In the first section, the findings related to different factors that influence the AMU of farmers and veterinarians from Manuscripts I-III are compared to previous literature, and relevant future implications hereof are discussed.

5.1.1 A farmer- and veterinarian-specific approach

Manuscript I illustrated that while factors influencing veterinary and farmer AMU could be similar, in many cases they were diverging. Therefore, the overall finding of this review study was the need for communication between the veterinarian and the farmer to identify each other's position within their complex and interacting networks of influencing factors, e.g. to explicitly define their own understanding of AMU through dialogue. Manuscripts II and III further focused on the factors influencing farmers' and veterinarians' AMU choices, respectively, under Danish conditions. Similarly, Manuscript II concluded that the interviewed farmers had quite different perceptions on e.g. how to approach treatment, implications of the current farm setting and the role of the veterinarian. These conclusions reinforce the idea that the practising veterinarian cannot take a one-size-fits-all approach to changing AMU across the farms where he/she offers VHHC. Manuscript III identified the need for communication in terms of the dual roles of being an authority (exemplified as a "police officer") and advising veterinarian (e.g. a trustworthy partner). Furthermore, different approaches to treatment as well as approaches to nudge or confront the farmer to change behaviour were identified among the interviewed veterinarians. As such, all three manuscripts supported the veterinarian-farmer-specific, communication-rich and co-creative approach to VHHC with a focus on understanding each other's perspectives on AMU to create a good environment for working towards AMU reduction.

As highlighted in the study context section of this thesis, previous and recent studies have similarly highlighted the need for such a farmer-veterinarian-specific approach to VHHC, not only related to AMU reduction (Andersen, 2004; Klerkx and Jansen, 2010; Lam et al., 2011; Derks et al., 2012; Duval et al., 2017; Bard et al., 2019; Svensson et al., 2019b; Shortall, 2021). However, approaches to AMU reduction within the Danish VHHC setting might differ slightly from these more general perspectives. This is because there are some additional aspects related to AMU reduction, as achieving rational AMU within VHHC is a duty imposed by society due to the (distant) risk of AMR emergence. Of course, the farmer and the veterinarian may also have a personal interest in achieving rational AMU, however, as identified in Manuscripts II and III, the interviewed Danish farmers and veterinarians rarely encountered AMR. As such, a personal interest is not thought to be the primary driving force for changing AMU within VHHC. Therefore, the starting point for changing behaviour is quite different than for other herd health or production-related issues usually addressed within the VHHC. For example, Bard et al. (2019) introduced the concept of "benevolence", i.e. the advising veterinarians' true motives for engaging in the VHHC, how these might be perceived by the farmer and how that might affect the collaboration. As identified in Manuscript III, the interviewed veterinarians struggled to balance their two roles related to AMU reduction on the farm: the police officer who needs to control AMU and the advising veterinarian with the farmer's/animal's/their own interests in focus. This struggle was potentially caused by simultaneously taking on two roles with such different motives, thus compromising the veterinarians' trustworthiness and ability to show benevolence towards the farmer. As such, there appeared to be a boundary in terms of responsibilities and duties in relation to controlling AMU, which may make it difficult for the veterinarian to convince the farmer about his or her true benevolence towards the farm in question. Consequently, the farmer might be less trusting of the advice given by the veterinarian and this might generally undermine their relationship and the veterinarian's ability to motivate the farmer to change (Svensson et al., 2018; Bard et al., 2019).

Another aspect that might specifically relate to changing AMU within the VHHC is the communication style adopted by the interviewed veterinarians in Manuscript III, i.e. the confrontational and the nudging approach. This might be relevant to changing AMU due to the above-mentioned control tasks imposed on the veterinarian and the feeling of uneasiness related to demanding that the farmer changes his or her AMU behaviour. These tasks might encourage the veterinarian to deal with it quickly through a confrontational approach or to try to avoid an unpleasant confrontation with the farmer by instead accepting slow adaptive steps (and potential detours) in order to make them change their behaviour. However, recent research on veterinarians' communication styles could indicate that these approaches – or at least the confrontational style (Bard et al., 2017; Ritter et al., 2018; Svensson et al., 2019a) – might be more common among practising veterinarians within VHHC and may be based on historic socialisation from a paternalistic advising culture (Hegelund, 2004).

Svensson et al. (2019a) proposed the use of motivational interviewing as a tool to increase the value of VHHC for farmers. Issues related to integrating motivational interviewing as a tool to change AMU within VHHC could, however, be contradictory: can an issue like reducing AMU, which has been imposed from above in Denmark, be addressed meaningfully through motivational interviewing? Motivational interviewing implies that change should be driven by an inner motivation and self-determination of what to change by the person who is subject to motivational interviewing (Bard, 2018). Furthermore, as emphasised by Bard (2018), motivational interviewing requires a considerable amount of training. However, setting aside these concerns, practising veterinarians might still benefit from adopting a different communication style – more akin to motivational interviewing. This approach includes avoiding criticising or blaming the farmer for their current AMU behaviour, asking open questions to allow the farmer to investigate his or her own perception and understanding of rational AMU, trying to understand the farmer's current reasons for resisting change and trying to engage the farmer as much as possible in the AMU change process (Bard, 2018). Taking such an approach might further aid the veterinarians in their efforts to fulfil both the controlling and advising roles within the VHHC.

The explorative approach in motivational interviewing mimics double-loop learning (Andersen, 2004) and "cold cognition" (Green et al., 2012) as presented in the study context section of this thesis, whereby the farmer goes through a reflective process. Allowing time for such reflections within the VHHC appears to be an important prerequisite for changing AMU. However, even though there may be room for reflection within the VHHC, an additional aspect that may complicate a change in AMU is the complexity in understanding AMR, as identified among the interviewed farmers in Manuscript II. In order to want to change AMU, it is necessary to understand why it is necessary to do so, as emphasised by Higgins et al. (2012) in Chapter 2 of "Dairy Herd Health". The practising veterinarians must therefore make AMR comprehensible and relevant to their farmer clients, and as emphasised in the study context section of this thesis, farmers each have different learning styles (Lam et al., 2011). Some might prefer experience-based learning (i.e. "accommodators" as in Lam et al.), and these farmers might benefit from seeing e.g. agar plates showing susceptibility testing of milk samples from a specific cow or farm to illustrate concrete and relevant examples of AMR. Such practical specimens can be used as a starting point for reflections and dialogue on rational AMU and AMR within VHHC. Similarly, proper presentation of the AMR issue should be considered according to other potential learning styles of the farmer in focus. Some farmers may be "assimilators" (Lam et al., 2011), i.e. have a scientific approach to learning. These farmers might change their AMU actions and attitudes based on a theoretical and informative talk on AMR given by the veterinarian, explaining the consequences of AMU. The veterinarian may be one informative source, but articles or websites may also be trusted sources (Lam et al., 2011). In addition, some farmers may be "divergers", i.e. learning from their own and others' experiences. These farmers may benefit from participation in e.g. Stable Schools, where they can discuss and weigh-up different practical approaches to AMU reduction with other farmers, as discussed in the next section (Lam et al., 2011).

In this section, achieving a change in AMU within the VHHC has mostly focused on the contribution by the veterinarian. However, as identified in Manuscript II, one of the interviewed farmers felt that he was the one initiating change processes among his advising veterinarians. As such, the proposed approaches to changing AMU within VHHC have no predefined direction: farmers might also use illustrative examples, information sources or motivational interviewing to convince their veterinarian to move towards rational AMU.

5.1.2 Stable Schools as an approach to reducing antimicrobial use

This second section of the discussion takes a starting point in the Stable Schools as a specific example of an approach to changing AMU behaviour that could be taken within the local setting of the VHHC collaboration. As such, a veterinary practice may gather some of their clients in a Stable School with the specific aim of working on AMU. This, in combination with the finding in Manuscript II that farmers were inspired by each other's AMU practices and attitudes, was taken as the starting point for investigating the potential to change AMU through Stable School participation in Manuscript IV.

As discussed in detail in Manuscript IV, the herds participating in the Stable School had a limited decrease in treatment risk over the one-year period. This finding is in contrast to results in previous studies on Stable Schools or Stable School-like projects with a focus on reducing AMU in participating herds. A reduction in AMU was achieved in these studies (Bennedsgaard et al., 2010; Ivemeyer et al., 2015; Morgans, 2019), however in some cases, economic and branding incentives were in place (Bennedsgaard et al., 2010). Reasons for a lack of AMU reduction are discussed in Manuscript IV. Some of these barriers to change (e.g. insufficient facilitation as well as farmers and employees experiencing periods of stress) were also mentioned in a pilot study on a modified Stable School in Germany (March et al., 2014), which also reported a limited effect on treatment incidence from Stable School participation. Like our study but in contrast to the study by Morgans (2019) and Bennedsgaard et al. (2010), this pilot study did not focus solely on AMU reduction. Therefore, the Stable School study of this thesis suggests that Stable Schools should have a clearly defined aim of reducing AMU, combined with a close follow-up of the goals set within the group to offer the best conditions for a change in AMU. However, despite a lack of this, one of the participants (P1 in Manuscript IV) expressed a changed attitude towards AMU, and overall, all of the participants expressed satisfaction with their participation and what they had gained from it.

One concern about the Stable School approach that I encountered while conducting this PhD was raised by practising veterinarians. Some veterinarians who had considered establishing a Stable School and engaging as facilitators were worried that improper or even harmful management or treatment procedures could be shared and adopted by participating farmers. They considered this to be an issue because as facilitators, they would become aware of it without having the opportunity to correct it if they were to comply with the non-expert role. A solution to this issue has been presented in the paper by Hansmann et al. (2020), where both an expert and the facilitator were present at the Stable School meetings. According to the findings of the paper, this did not introduce power asymmetry issues (Hansmann et al., 2020), which according to Noe et al. (2015) could be of concern when experts (e.g. often academics) and farmers (e.g. non-academics) interact. Even though power asymmetries did not seem to be an issue, I would argue that the practising veterinarians would have the opportunity to correct any harmful management procedures either at the end of the meeting or at a later VHHC visit at the herd. The focus should be on maintaining a safe, confidential and equal learning environment at the meeting, as highlighted by the participants in Manuscript IV, and the facilitator should not correct or interfere with suggestions given at the meeting unless the advice is clearly against the law, instead waiting until after the meeting to contribute scientific corrections. The practising veterinarian might have to learn to appreciate the change processes initiated among the Stable School participants, even though the actions may be scientifically incorrect, and instead perceive the situation as an opportunity to change the farmer's mindset further. Small adaptive changes can therefore be initiated over time instead of applying best practice immediately.

As mentioned in Manuscript IV, a Stable School will definitely not suit all farmers, as some might appreciate e.g. receiving advice from experts. It is therefore the practising veterinarian's responsibility to recruit suitable participants for the Stable School, guided by their in-depth knowledge of the learning styles and needs of their clients. Furthermore, the practising veterinarian should keep in mind the identified barriers to change related to the Stable School (Manuscript IV) during the planning phase, i.e. they should consider the group composition, the establishment and maintenance of a common goal within the group, as well as how the group should be facilitated. This thesis suggests that Stable Schools comprise a useful tool within the local setting of VHHC for engaging in dialogue and perhaps changing AMU attitudes and/or practices among conventional dairy farmers if planned and executed prudently.

5.1.3 Evaluating antimicrobial use over time

Focusing on change of AMU from a local perspective requires valid evaluation methods to demonstrate whether AMU reduction or refinement has actually been achieved. Such an evaluation might have multiple purposes. For example, the following four purposes of an AMU evaluation could be relevant to the VHHC setting:

1. The veterinarian and farmer might want to know whether a within-herd reduction in AMU has been achieved.

2. The veterinarian might want to evaluate AMU across herds for benchmarking purposes in order to motivate farmers (Sumner et al., 2018).
3. The veterinarian and farmer might work towards refining AMU and may therefore be interested in knowing whether they have achieved this.
4. The veterinarian might have suggested a specific intervention thought to influence AMU, and the veterinarian and farmer might be interested in knowing whether the intervention had the expected influence.

It is important to establish the purpose of the AMU evaluation as this will determine a suitable evaluation method. For some AMU evaluation purposes, state space models for monitoring treatment risk over time as presented in this thesis could be a useful tool for evaluating AMU at the herds. However, they will not be suitable for all evaluation purposes, as discussed in the following section.

For the first purpose stated above, the veterinarian and farmer could be interested in knowing whether the overall AMU of the herd decreased over time, for example after working explicitly on AMU reduction for a certain period. In this case, the inventory of ADD per 100 animals per day as calculated by VetStat would be one way to obtain an estimate of the development in AMU over time (Jensen et al., 2004). However, there is a delay involved in calculating ADD per 100 animals, and stocking/purchasing patterns can lead to bias. Alternatively, the farmer and the veterinarian could look at raw data of how many antimicrobial treatments had been initiated over time and use initiation of treatment as a proxy for AMU. Both of these evaluation methods (ADD per 100 animals and raw treatment data) could be biased, for example, by a higher number of cows at high risk of infection post-partum being present in the herd at a certain time, potentially causing a higher demand for treatment during that period. Neither the ADD per 100 animals, nor treatment registrations over time would take this into account, which could complicate comparison over time within the herd. For that reason, this thesis proposed the use of state space models (i.e. a DGLM for monitoring treatment risk), as they are able to take into account influencing factors such as season (indirectly) and distribution of parities and stages of lactation over time. However, no AMU evaluation methods are perfect, and the developed DGLM also has some limitations. For example, it requires the correct identification of diseases suspected to involve antimicrobial treatment. If not correctly identified, the graphs showing the probability of treatment will be a potential under- or overestimation of the true AMU at the herd. However, as long as the criteria for diseases involving antimicrobials does not change over time, within-herd comparisons should be justified.

Also related to the first purpose of a within-herd evaluation of AMU reduction, the veterinarian and farmer might be interested in knowing not only if AMU was reduced, but also if herd health and production were maintained simultaneously. The inventory of ADD per 100 animals per day would need to be combined with other herd-specific data to draw such a conclusion. One opportunity could be to look at developments in raw data on e.g. somatic cell count (SCC) and mortality records. However, as mentioned above, these data might be biased. Another alternative is the use of state space models, yet these are also subject to some limitations since they have only been developed for certain outcomes, i.e. SCC in bulk tank milk (Thysen, 1993), milk yield (Van

Bebber et al., 1999, Manuscript V), insemination and conception rates (Cornou et al., 2014) and treatment risk (Manuscript V). As such, production might be evaluated concurrently with reductions in AMU through the DLM on milk yield, as presented in Manuscript V. However, a proper evaluation of herd health based on the above-mentioned outcomes cannot be justified, as it would require a range of outcomes to be evaluated simultaneously, e.g. SCC for individual cows, the reproduction parameters presented by Cornou et al. (2014) and other good proxies for animal health. An alternative herd health indicator is the clinical screening of cows during high risk periods (Enevoldsen, 1993; Krogh, 2012).

If the purpose was for the veterinarian and farmer to compare AMU at a specific herd with the AMU at other herds, e.g. for benchmarking purposes, which has previously been found to motivate farmers to change their behaviour in relation to calf management (Sumner et al., 2018), it would be problematic to use the inventory of treatment data – either as raw data or analysed using a DGLM for treatment risk. This is because the treatment data would represent the farmer's management choices in terms of when his animals need treatment, and these treatment criteria might vary greatly among farmers, making the inventories incomparable (Vaarst, 2005; Lastein et al., 2009). The same applies to the ADD per 100 animals per day, and therefore no perfect evaluation method for benchmarking purposes exists. Instead, the veterinarian should be careful to compare ADD per 100 animals per day only among herds with similar treatment criteria.

If the purpose was to evaluate whether AMU refinement was achieved in a specific herd, other evaluation tools would be needed. Examples of a refinement that would not necessarily imply a reduction in AMU could be a change in the specific type of antimicrobial used. Another example could be an extended treatment period for e.g. clinical mastitis caused by *Staphylococcus aureus* or *Streptococcus uberis* to ensure bacterial cure, or using dry cow therapy to a larger extent to cure mastitis cases occurring in late lactation (Krömker and Leimbach, 2017). These refinements and changes in AMU would therefore not be captured by the raw treatment data or the DGLM for treatment risk. Instead, they would require qualitative follow-up with the farmer to identify these changes in treatment practices. The DGLM for treatment risk would capture some changes in use patterns if the model specifically analysed udder treatments rather than all treatments, as when estimating the intervention effect of applying teat sealers in Herd 1 in Manuscript V. It would then be possible to calculate the probability of udder treatment across different parities and for different stages of lactation, modelling it so that the probability of udder treatment could change relatively within different parities and stages of lactation. However, the limitation of looking at only one type of treatment is that there are very few observations to support the analysis, which would increase the uncertainty about the parameter estimates. Refining AMU could also imply an overall reduction in AMU, e.g. by using anti-inflammatory drugs as an alternative to antimicrobial treatment in some mastitis cases (Royster and Wagner, 2015; Krömker and Leimbach, 2017; Krömker et al., 2021). In conclusion, alternative evaluation methods must be used to determine AMU refinement, for example, a combination of treatment data, qualitative data and statistical analysis could be used.

If the purpose was to evaluate whether a specific intervention reduced AMU, the DGLM could be used as proposed in Manuscript V. However, the DGLM as well as other statistical methods can only be applied under certain (stable) herd conditions and does not ensure causality of the association, i.e. we cannot be certain that the intervention does indeed cause the changes in treatment risk. Instead, the intervention could be planned as a randomised controlled herd trial, and the effect could be estimated using a DGLM, similar to Stygar et al. (2017).

To conclude this section, the most suitable method for evaluating AMU at dairy herds depends greatly on the purpose of the evaluation. The state space models presented in this thesis might be beneficial for the within-herd evaluation of AMU. However, the models currently have limitations in relation to the number of outcomes they can evaluate and in evaluating AMU refinement. Furthermore, as presented in Section 4.4.1, the applicability of the state space models (as well as other statistical methods) is greatly dependant on the herd-specific conditions. The models will make inaccurate predictions during periods with varying levels of treatment risk or milk production. However, the DGLM might be sufficient for within-herd evaluation of AMU (treatment risk), as it will learn from the deviating predictions. Therefore, the retrospective evaluation of treatment risk by the veterinarian and farmer will be sufficiently precise, at least compared to other potentially biased measuring methods. However, for other purposes of AMU evaluation, different methods such as ADD per 100 animals per day or raw data analysed using simpler statistical methods such as statistical process control are still useful (De Vries and Reneau, 2010; Krogh, 2012). These simpler statistical methods, however, might not be able to take multiple risk factors and autocorrelation into account, and they would be non-dynamic.

5.2 Changing antimicrobial use within veterinary herd health consultancy from a structural perspective

Although the focus of this thesis is on the working relationship between the veterinarian and farmer through VHHC, some of the findings in Manuscripts I-V are relevant to VHHC but point to structural challenges that lie beyond the control of the individual farmer and veterinarian. It is important to address and discuss these structural challenges since they influence the veterinarian and farmer in the VHHC and their opportunity to change AMU from the outside.

5.2.1 The empowerment of newly educated veterinarians

In Manuscript III, one of the central conclusions was a need for evidence-based research on AMU that is applicable in a local farm context in order to empower newly educated veterinarians in their AMU choices and minimise the reliance on personal experiences among their more experienced colleagues. However, reflecting on how this evidence-based research on AMU should empower newly educated veterinarians raises some structural concerns, e.g. will the mere development of this type of research ensure empowerment of newly educated practising veterinarians in their AMU choices as stated in Manuscript III?

A study by Vandeweerd et al. (2012) further nuances these reflections. They identified a deficiency in veterinary education, i.e. the practical application of an evidence-based approach was lacking. Therefore, the newly educated veterinarians had trouble prioritising the many treatment options they were theoretically aware of when in a veterinary practice where quick decisions needed to be made (Vandeweerd et al., 2012). Furthermore, Proctor et al. (2011) described how newly educated veterinarians must learn to navigate the need to translate textbook science to field-generated and experience-based knowledge before farmers will perceive their advice as valuable, i.e. learning to work with an evidence-based practice at herd level, as introduced by Lastein (2012). These challenges were not explicitly mentioned by the newly educated veterinarians interviewed in Manuscript III, yet they did express a discrepancy between their colleagues' AMU choices and their theoretical knowledge of how to use antimicrobials, as taught at the university. Furthermore, this discrepancy made them comply with their immediate peers' preferences out of fear of e.g. being dismissed from their job. This finding might point towards a structural challenge within veterinary education and/or veterinary practice similar to that identified in the study by Vandeweerd et al. (2012), i.e. that Danish veterinary students may not be equipped to integrate their knowledge on AMU when they complete their education. Therefore, merely developing evidence-based research on AMU does not necessarily imply that newly educated veterinarians will be able to apply these research results as practising veterinarians because they lack the power and practical knowledge on how to do so.

Their more experienced colleagues might be quicker to implement the requested evidence-based research on AMU because they may have more experience in conveying this type of research within a local farm context. In that sense, they newly educated veterinarians might experience fewer discrepancies between their own knowledge about AMU and their colleagues' AMU choices. However, if the goal is to support and empower newly educated veterinarians so that they can resist farmer preferences and ingrained habits, it will be necessary to improve the transition from veterinary student to practising veterinarian. It might therefore be relevant to consider the concept of apprenticeship, as described by Lave and Wenger (1991). In veterinary practice, more experienced colleagues' training newly educated and recently hired veterinarians in how to convey evidence-based research within a local farm context resembles the concept of apprenticeship. However, apprenticeship within veterinary practice does not necessarily resemble that of a scientist, as described by Kvale (1997), but rather that of a craftsman. Training within a veterinary practice primarily supports the acquisition of new practical skills (i.e. treatment of diseases), as described by some of the interviewed veterinarians in Manuscript III, rather than acquiring the complex intellectual skills of the veterinary profession, such as gathering, analysing and conveying evidence-based knowledge in an engaging way with local meaning to farmers.

Therefore, there seems to be a need to rethink the Danish veterinary curriculum related to VHHC through pragmatic and practical approaches, e.g. by ensuring the course includes apprenticeship programmes with a focus on acquiring the intellectual skills of the veterinary profession, including good communication skills, or by rethinking the current form of apprenticeship in veterinary practice so that newly educated veterinarians are trained by their colleagues to convey evidence-based research on e.g. AMU in a local farm context, potentially in collaboration with the university through post graduate supervision (Kvale, 1997; Proctor et al., 2011; Lastein, 2012). This might ultimately empower newly educated veterinarians in their ability to resist the pressure to prescribe certain antimicrobials imposed on them by their colleagues or clients.

5.2.2 Level of legislation on antimicrobial use

Manuscript I revealed that legislation was an influencing factor in both the farmers' and veterinarians' motivation to change AMU within the VHHC. It was identified as an extrinsic factor, thus influencing a change in AMU within VHHC from the outside. Similarly, the findings of Manuscripts II and III supported that the current Danish legislation on AMU influenced veterinarians' and farmers' AMU practices and attitudes. According to the interviewed farmers, legislation determined their everyday actions but was also outside their immediate control, and the interviewed veterinarians perceived legislation as a contextual factor that influenced how and when they used antimicrobials. Therefore, legislation will be discussed from a structural point of view in relation to its influence on changing AMU within VHHC.

In Manuscript I, diverging views on the sufficient level of legal control for AMU were found in the literature included in the review. This appeared to depend on the current national AMU legislation in the specific country, as discussed in detail in Manuscripts I, II and III. The high level of legal control over AMU under Danish conditions is seen in few other places, and it is likely that the findings from the interviews with veterinarians and farmers in Manuscripts II and III are specific to a Danish context.

The interviewed veterinarians and farmers in Manuscripts II and III had differing opinions on the influence of the current Danish legislative framework on AMU within VHHC. All interviewed farmers acknowledged the need for legal control of AMU, a finding that has been similarly identified among Finnish farmers, who perceived legal control of e.g. animal welfare as a necessity (Väärikkälä-Kiilunen et al., 2018). However, the farmers in Manuscript II were subject to very different levels of legislation depending on their type of production, which was reflected in their attitude towards legislation on AMU. Organic farmers were subject to the most restrictive legislation and sector codes of production, and many of the interviewed organic farmers perceived this positively and as an assurance of quality for consumers. In contrast, medicine use was liberalised in 2006 for conventional farmers, and some of those interviewed believed that AMU was legitimate and at times necessary. In Manuscript III, the interviewed veterinarians also expressed different opinions on how the liberalisation of medicines had influenced AMU among farmers. Some expressed the view that it had refined AMU in a positive way, whereas others alluded to increasingly less prudent AMU.

A pilot project was conducted in 2004-2005, prior to deciding whether farmers should be given access to medicines. This was to evaluate the potential effects of initiating such legislation (The Danish Veterinary and Food Administration, 2008). After the one-year project period, an external assessor conducted an evaluation. Across the 117 dairy herds that participated in the pilot project, an overall initial increase in medicine use was identified, followed by a decline (except for over the winter months) (Hill, 2005). However, the data available for the evaluation were insufficient to draw conclusions on the expected long-term effects on AMU (Hill, 2005). A few years after implementing the liberalisation of medicines, the Danish Veterinary and Food administration conducted an evaluation in collaboration with the Danish Veterinary Association and the Danish cattle sector (The Danish Veterinary and Food Administration, 2008). At that time, the Danish Veterinary Association expressed general satisfaction with the legislation because a preventive focus on herd health within VHHC was supported through the frequency of veterinary visits. However, concerns were also expressed about the bureaucracy accompanying the permission to use medicines in terms of regular reports and the control of medicine use. Identical concerns were raised by the Danish cattle sector, but these were directed towards the required treatment registrations (The Danish Veterinary and Food Administration, 2008).

The interview studies for Manuscripts II and III were conducted 11 years later in 2019, however, some of the interviewed veterinarians and farmers continued to express similar concerns. Furthermore, the interviewed veterinarians exhibited decreased motivation and self-determination in their VHHC work because of the many required legislative tasks. This finding is similar to a concern expressed by researchers in the UK in relation to increased legal control of AMU (Buller et al., 2015). As described by Buller et al. (2015), when legislation plays an increasing role in controlling AMU, there is a risk that it will come at the expense of self-determination among veterinarians and farmers. The effect of increased legal control has also been investigated in other areas. Vaarst and Fisker (2014) expressed a similar concern about farmers' decreased motivation to participate and thus contribute when Stable Schools were made mandatory in official Danish legislation on VHHC in 2010. Atkinson and Neale (2008) emphasised the importance of expressing and communicating the value of herd health plans when VHHC was made mandatory for organic farmers in the UK, otherwise the increased legal control would just lead to tick-box conformity.

Similarly, there seems to be a need to rephrase the value of legal control of AMU and the predefined tasks accompanying the high level of legislation under Danish conditions. Alternatively, if we do not want to accept a lack of motivation and self-determination caused by the current level of AMU legislation, discussions should be initiated on how Danish AMU legislation should be balanced, and potential alternatives to the current setup should be investigated. This should ultimately avoid hesitancy and lack of ownership among practising veterinarians and feelings of futility and tiresome bureaucracy for both farmers and veterinarians. As illustrated in the report by the Danish Veterinary and Food Administration, this has been an ongoing discussion under Danish conditions already for several years.

Finally, the characteristics and understanding of AMR add to the complexity of perceiving and phrasing AMU legislation as valuable. As identified in Manuscripts II and III, interviewed farmers and veterinarians both perceived AMR as an abstract threat not relevant to their daily lives. Therefore, acknowledging and accepting a high and intrusive level of legislation within an area of distant relevance can be difficult. Furthermore, the interviewed veterinarians believed they were automatically addressing AMR by complying with the current legislation (Manuscript III), and legislation might therefore have had an adverse effect on Danish veterinarians' awareness of AMR. This specific finding of "automatically accommodating the risk of AMR" was not identified in the extensive literature review conducted by Farrell et al. (2021), indicating that this perception may be specific to a context with a high level of AMU control. To remind each other about the value of AMU legislation within the VHHC due to its interconnectedness with the risk of AMR, it might be beneficial for the practising veterinarian and the farmer to reflect and initiate dialogue on the importance of rational AMU to minimise AMR. Furthermore, these reflections might reinforce the veterinarians' and farmers' motivation and self-determination, as well as facilitate communication about when and why the role as "police officer" is adopted by the practising veterinarian, as discussed in Manuscript III. Using communication and reflections to solve the issue of uneasiness among farmers when being supervised (either by the authorities or the practising veterinarian) has previously been identified within the area of animal welfare – another issue that is complex to supervise, not because it is difficult to comprehend like AMR, but because multiple perceptions of good animal welfare exist (Anneberg et al., 2012; Väärikkälä-Kiilunen et al., 2018).

5.3 Methodological considerations

The following sections will discuss the strengths and limitations of the chosen methodological approaches of the thesis, as well as their implications.

5.3.1 Considerations of the model framework used in the review study

A socio-ecological model developed from the Theory of Planned Behaviour (TPB) (a social cognition model of health behaviour) to include extrinsic factors was used in Manuscript I to categorise and give an overview of factors influencing veterinarians' and farmers' motivation to change their AMU. However, the distinction between intrinsic and extrinsic factors was not as straight-forward as the model might suggest, as many of the factors could be placed within several categories in the model. For example, the influencing factor of personal experience was associated with "social norms", "self-efficacy", "personal beliefs and attitudes" and "treatment culture". This ambiguity in correctly placing influencing factors within the available factor categories is supported by criticism of the TPB in previous literature (Oliver and Berger, 1979; Sniehotta et al., 2014). For example, Sniehotta et al. (2014) criticised the TPB for being too simplistic and not including all types of factors influencing human behaviour, e.g. intention to change is not always a prerequisite for change. These critique points were recognised as part of the analysis in Manuscript I, even though the model had been extended. However, the model was chosen to give an overview of all influencing factors and as such, the exact categorisation of the factors was less relevant than the identification of factors and their interaction. It is therefore expected that the findings of Manuscript I will not be affected by the choice of model.

5.3.2 Qualitative methods

Several potential sources of bias and reasons for decreased trustworthiness of the qualitative studies conducted as part of this thesis (Manuscripts II, III and IV) have been identified. These potential methodological limitations and their implications will be discussed in the following section.

Considerations on the trustworthiness of the interview studies

A higher degree of objectivity could have been achieved in the interview studies conducted for Manuscripts II and III by allowing multiple manuscript authors code the transcripts. Having agreement across independent coding would increase the reliability of the results. Furthermore, returning transcripts to participants for them to correct or add any information would have been another way to increase the objectivity of the studies. Since transcribing the recordings was a time-consuming procedure, they could not be returned to participants until a year after the interviews were conducted. Therefore, returning the transcripts risked a situation where the interviewees no longer identified with their central statements and asked for them to be deleted. This, however, would not necessarily mean that the statements were irrelevant at the time of the interview. As a result, we chose not to return any transcripts to the participants. Despite not complying with these additional elements that could have increased objectivity, the trustworthiness of the interview coding and analysis was still considered sufficient. This was because the coding and analysis process was closely overseen by the co-authors, and an initial calibration of the coding procedure was performed by me and one of the co-authors who had a great deal of experience in qualitative research. In cases of doubt, the coding and analysis were discussed by the co-author group.

Considerations on trustworthiness in the qualitative elements of the Stable School study

Collaboration with a veterinary practice in this Stable School study was beneficial as it allowed me to monitor and observe the process independently, as opposed to facilitating the Stable School myself. However, the practising veterinarians had limited experience of facilitating Stable Schools, which could be seen as a disadvantage. As mentioned in Manuscript IV, the primary facilitator had previously facilitated a number of Stable Schools, but the secondary facilitator had no previous experience, and neither had facilitation training before the start of the study. This lack of experience might have resulted in some of the identified barriers for change related to the Stable School, as introduced in Manuscript IV, e.g. facilitators sometimes struggling to follow the formal framework of the Stable School. Trained facilitators are available and could have been used instead. However, despite the barriers introduced, having a veterinary practice facilitate the Stable School was beneficial as it resembled the real-life situation in many Danish veterinary practices that might be interested in offering Stable Schools as part of their advisory services. Any veterinary practice wishing to facilitate a Stable School would need to accommodate it in their daily work with their current facilitation competencies, and their already established relationship with their clients in other advisory contexts. Therefore, the results of this research could be seen as being relevant to the local reality of a veterinary practice. In addition, there are no guarantees that a trained facilitator would not introduce different barriers by facilitating the Stable School.

In relation to the observations, my background as a practising veterinarian meant that I had a scientific understanding of what was discussed at the meetings and in the conversations among participants. Furthermore, my knowledge of how veterinary consultancy visits and Stable Schools usually proceed gave me a preunderstanding that I needed to be aware of, while also providing me with potential explanations for some of the informal guidelines and dynamics observed in the group. This preunderstanding could decrease objectivity and thus the trustworthiness of the observations if not continually reflected upon throughout the process. Therefore, after each observed Stable School meeting, I made notes on (among other things) my own influence as a researcher on the group and what influence my preunderstanding might have had on what I had observed.

Having a completely passive observer role was naturally difficult since my engagement in all the meetings and small talk with participants before “stepping in and out” of the meetings meant that the participants and facilitators perceived me as part of the group. However, they were all aware of my purpose for being there and my continuously passive presence gradually established my role in the group, i.e. they never expected any input from me at the meetings. It is not possible to claim that my presence had no influence on the participants and the facilitators. However, I believe that a trusting relationship was established with the participants, which was important for them to feel secure enough to share experiences and attitudes that they might have believed I would perceive as wrong. As such, the influence from my presence was minimised, and social desirability bias was not suspected, although it was not explicitly proven to be absent.

Furthermore, being part of a group that continuously interacted with each other over a longer period also meant that the participants might have withheld perspectives related to the other participants' behaviour or presence within the group when being interviewed. They might have done so because they did not trust my ability to maintain confidentiality, or because they knew that the results would be reported at the end, thus presenting uncertainty about what might be shared and whether this information could be traced back to them. Ultimately, this retention of information could be driven by a fear of introducing a bad atmosphere within the group or being in bad standing with some of the other participants. This information retention could imply that I obtained a skewed perspective of the Stable School dynamics. However, during the interviews, I experienced that the participants and facilitators shared perspectives related to the other participants in a polite and constructive manner. In addition, observing the Stable School meetings gave me an opportunity to confirm the group dynamics as expressed at the interviews.

The triangulation conducted in Manuscript IV revealed trends in the quantitative data that could not be explained by the collected qualitative data. As such, there appeared to be a need for even more frequent interviews and/or observations. Had the monitoring graphs been available to the participants while the Stable School was running, I would have been able to return Figures 1-8 of Manuscript IV to the participants for their comments so that together we could have reflected on the reasons for e.g. increases in treatment risk. This would also mimic the approach taken by the practising veterinarian within the VHHC when unexplainable trends in herd data are detected and need to be elaborated by the farmer. Furthermore, an additional validation of the findings of the triangulation would have been possible, e.g. the identified changes could have been confirmed or rejected by the participants. This validation step could have been performed at any later stage, and not just during the Stable School. However, this was not a possibility due to limitations in the duration of the PhD study period.

In conclusion, the qualitative parts of this thesis have some methodological limitations. The interview transcripts of Manuscripts II, III, and IV were not returned to the participants for validation, nor was the coding conducted by several individuals independently. In addition, the use of participant observations introduced the risk of social desirability bias, even though this was not suspected because a trusting environment had been established. Furthermore, the findings of the triangulation in Manuscript IV were not validated even though this might have been beneficial. Therefore, the current methodological approach may not have captured all relevant findings, and those identified might not all be accurate.

5.3.3 Quantitative methods

Several potential sources of bias in the quantitative methods used in Manuscripts IV and V have been identified. These potential methodological limitations and their implications have been discussed in detail in Manuscript V, but a short overview will be given in the following section.

As already highlighted in the discussion on AMU evaluation methods (Section 5.1.3), the developed state space models have some limitations in terms of their applicability to certain situations. As discussed in Manuscript V, many changes happened simultaneously in the two herds used for effect estimation (Herds 1 and 6 in Manuscript IV and Herds 1 and 2 in Manuscript V), and the interventions investigated had a non-specific onset, partly why it was not possible to answer the basic question of causality, i.e. confounding bias was present. These unstable conditions could also be reflected in the validation of the two models (Section 4.4.1), where the forecast errors were correlated, potentially implying that the treatment risk and milk yield varied significantly over time in the two herds or that season should have been specifically implemented in the model. Therefore, the effect estimation findings should be interpreted with caution. As emphasised in Manuscript V, the application of state space models for effect estimation and/or monitoring should be considered carefully according to the type of herd under investigation, the data available and the characteristics of a potential intervention to be evaluated.

Even though the state space models have certain limitations, they still provide a valuable tool compared to other simpler statistical tools such as e.g. calculations of incidence risk or rates, regression models, random effects models or statistical process control. These simpler statistical tools would also be associated with the limitations mentioned for the state space models. However, in contrast to these simpler statistical tools, state space models handle biases often present in the dynamic dairy herd: they take autocorrelation and herd dynamics into account in a time series approach, and credible intervals for all model parameters are estimated at every time step so that the certainty of the provided estimates can be evaluated. However, a disadvantage of state space models according to the simpler statistical approaches is the many assumptions that should be fulfilled before the models can be applied sufficiently, for example that the forecast errors are assumed to follow a known distribution, and that they are independent. The dairy context does not always provide a setting where state space models can be applied without breaking these assumptions, as seen in Manuscript V. However, there is currently no perfect statistical tool, but rather, the approach should be to combine the available tools in the best way possible. For example, simpler statistical tools such as a process behaviour chart could be used for explorative analysis, and then more complicated statistics such as state space models could be used for quantification or predictions, as suggested by Krogh (2012).

However, the state space models presented in Manuscript V have room for improvement to make them even more applicable. Suggestions to improve the state space models include allowing them to learn directly from seasonal patterns. This might improve the predictive capability of the model, thus minimising the correlation of the forecast errors and improving the model fit. Another suggestion would be to allow interaction between parities and stages of lactation in the DGLM for treatment risk so that changes in the relative probability of treatment over time can be detected. The treatment risk model could also be improved by presenting the predicted number of treatments as one line per herd so that confidence intervals could be added to the graphical presentations. That way, it would be easier to judge whether the probability of treatment at herd level changes significantly over time.

5.3.4 External validity

Different ideas about generalisability are relevant to the different study elements conducted in this thesis. These will be discussed in the following section, in combination with the generalisability of the overall findings of the thesis.

In terms of the qualitative interviews conducted for Manuscripts II and III, the aim was not to produce generalisable quantitative results, but rather to obtain thick descriptions of the topic, i.e. Danish veterinarians' and farmers' AMU practices and attitudes. Since the description of the interview results given in Manuscripts II and III are detailed and described within a context, I argue that analytical generalisability can be claimed (Kvale and Brinkmann, 2014).

In relation to the Stable School study, the focus was not on producing evidence generalisable to the total population of dairy herds participating in Stable Schools. Had this been the purpose, a much larger sample size of Stable Schools randomly selected from all types of dairy herds and across the entire country would have been required. Rather, the focus was on producing local evidence, i.e. a thick description of the potential for a Stable School to instigate changes in AMU, health and production from a longitudinal perspective. As such, the detailed descriptions of how the participants instigated changes during the Stable School (or why they did not) can be used as inspiration for other veterinary practices wishing to start up a Stable School.

The findings of the review study conducted in Manuscript I are generalisable depending on the context to which they refer. The literature concerned intensive dairy production, and not all of the factors identified were equally relevant in all countries. Therefore, the findings comprise an overview of the elements that could be relevant to motivating a change in AMU within VHHC internationally, but the specific relevance of the individual factors lies with the judgement of the individual stakeholder who might be interested in applying the findings in another setting.

As outlined in the study context section of this thesis, an explicit focus on the Danish VHHC collaboration may imply that the findings of the thesis are not applicable to the farmer-veterinarian collaboration framework in other countries. However, as emphasised, even though VHHC as defined in this thesis might be outside legal regulation and used to a limited extent in other countries, the specific content of the VHHC collaboration may still be quite similar. Therefore, I argue that because the VHHC in focus has been clearly defined and described in this thesis, the reader will be able to evaluate whether the findings might be relatable to his or her own specific context. Clearly, some unique conditions apply to the Danish setting, e.g. the current relatively low level of AMU compared to other European countries (European Medicines Agency, 2021), the high level of legal control and the large proportion of organic dairy production. These unique conditions are reflected in the findings, so they cannot be transferred directly to other contexts. However, they can initiate deliberations about the potential effect of approaches to changing AMU if used in other national settings.

6 Conclusions

In response to the objectives of the thesis concerning the potential for changing attitudes and actions related to AMU in dairy cattle production within the Danish VHHC context, we can conclude that:

1) according to international literature, a variety of factors influence veterinarians' and farmers' motivation to reduce AMU within the VHHC. The factors that influence veterinarians and farmers are at times identical, but often they differ. Furthermore, they are dependent on the country in which the veterinarian and farmer operate. Therefore, communication to understand each other's perspectives on AMU is important to support AMU reduction within the VHHC setting.

2) AMR is often perceived as a distant threat rarely present in the daily lives of interviewed Danish farmers and veterinarians, which is in agreement with similar findings in the international literature. There is a need to empower newly educated veterinarians to help them oppose the counterproductive preferences of farmers and/or colleagues and thus minimise the influence of personal experience on AMU practices. In addition, more locally relevant evidence (e.g. research) of treatment options or AMU approaches should be made available. Furthermore, there should be a smoother transition from veterinary student to practising veterinarian so that veterinarians can acquire communicative and intellectual skills associated with conveying e.g. evidence-based research on AMU to farmers in a meaningful way.

The AMU practices and attitudes of Danish veterinarians and farmers are influenced by legislation, which was found to introduce hesitancy and reduced motivation and self-determination within the VHHC as well as an automated and distanced attitude to AMR among some veterinarians. Furthermore, it challenged the veterinarians' ability to show benevolence towards the farmer due to their AMU control obligations.

3) the practical nature of the advice given at a Stable School and the safe and reflective environment established among participants makes participation a useful tool for initiating dialogue and potentially changing AMU attitudes and practices within the VHHC for farmers who are inspired by other farmers' AMU practices and attitudes. The value for the farmer depends on their preferred learning style and the current level of activity at the herd. However, an explicit common goal of AMU reduction should be set in the Stable School and accompanied by regular follow-up. Furthermore, the group should be facilitated in a balanced manner, and careful considerations about group composition and alignment of expectations are important.

The mixed methods approach to VHHC, as illustrated in the Stable School study, provides new insights and conclusions about trends in herd data in ongoing practical herd settings. As such, the practising veterinarian should make use of qualitative interview techniques and field notes (e.g. herd journals) in addition to quantitative evaluation of herd AMU, health and production data to make more precise assumptions about the causality of associations in relation to e.g. AMU reduction or refinement within the VHHC.

4) measuring AMU quantitatively is necessary to ascertain whether AMU reduction or refinement has been achieved. The choice of quantitative methods for evaluating AMU within the VHHC should be made based on multiple considerations. As a starting point, the purpose of the evaluation will determine the choice of method. For within-herd AMU evaluation, state space models may be a useful tool, used either on a monitoring basis or after implementing a specific intervention. However, during the implementation phase, it is important to consider the data available, the nature of the potential intervention in terms of onset and expected effect, and whether the herd conditions are relatively stable. These limiting herd conditions affect the application and interpretation of results for both state space models and alternative simpler statistical methods. However, state space models have additional strengths in terms of their approach to herd dynamics, but at the expense of model complexity. Therefore, the available methods should be carefully considered and selected according to the planned application and the situation at the specific herd, and the results should be interpreted accordingly.

7 Perspectives

The results of this thesis have identified the need for more evidence-based research on AMU and AMR. Future research should focus on the type of research results required to assist practising veterinarians with their everyday AMU choices in the best possible way. According to the Danish veterinarians interviewed, this research should be applicable within a local farm context. As such, the AMU research could for example be an evidence-based template with guidelines on how the practising veterinarians could themselves create valid evidence relating to how to use antimicrobials in a specific farm context, i.e. what diagnostic tests to perform and a list of antimicrobials and treatment regimens that should be prioritised for specific diagnoses. Therefore, diagnostic tests should be developed with a focus on efficiency, and the lists of preferred antimicrobials should be based on updated national results from surveillance of antimicrobial susceptibility testing. It is therefore recommended that a national surveillance scheme on antimicrobial resistance associated with common diseases within cattle should be developed. Further research is needed to determine the appropriate construction of such a surveillance scheme.

In addition, the results of this thesis suggest a need to renew the Danish veterinary curriculum within VHHC or the apprenticeship in veterinary practice so that newly educated veterinarians feel better equipped to oppose the AMU preferences of farmers and colleagues and incorporate their most recently acquired knowledge about rational AMU in veterinary practice. Future research could focus on how the transition from student to practising veterinarian can be improved, for example by investigating the potential of a one-year post-graduate training programme conducted in collaboration between the university and veterinary practice. In such a programme, the newly educated veterinarian should engage in practice work but without the full responsibility of an educated veterinarian. Furthermore, a collaboration between the veterinary practice and the university could ensure continuous training and supervision in communication skills and in conveying evidence-based research to farmers in a meaningful and useful way.

The work done in this thesis highlights the need for future considerations about the level of AMU legislation under Danish conditions. This should be done in light of the findings of this thesis, i.e. that some farmers feel distrusted by society due to the current registration requirements, whereas other farmers accept the current levels of AMU restrictions. Furthermore, some (primarily conventional) farmers perceive AMU as legitimate after the liberalisation of medicines in 2006. In addition, some veterinarians lack motivation within their advisory role and have adopted an automated response towards the risk of AMR. Relevant actors and stakeholders (politicians and representatives of practising veterinarians and farmers within the cattle sector) should come together to discuss the current AMU legislation and its consequences, as well as preferences for how future legislation should be shaped and its suspected influence.

Finally, the results of this thesis showed that farmers and veterinarians are influenced by social referents in their local environment when making AMU choices. As such, future research could investigate the potential in bringing together farmers and veterinarians with heterogeneous perspectives on rational AMU (e.g. conventional and organic farmers), in a setting that allows constructive and respectful dialogue that may result in an exchange of attitudes and practices. This may be within a Stable School or alternative setting, e.g. a Living Lab, as currently investigated in a European research project called “ROADMAP” (ROADMAP, 2020). A Living Lab is a participatory approach to change where relevant actors and stakeholders convene at monthly intervals over an extended period to discuss and initiate inclusive, practice-oriented and lasting changes in e.g. AMU (ROADMAP, 2020).

7.1 Considerations on implementation of findings within the veterinary herd health consultancy setting

To change AMU within VHHC, the results of this thesis suggest that practising veterinarians and farmers should take a reflective and dialogue-oriented approach, prioritising time and allowing for “cold cognition”. The opportunities to change AMU that lie within their individual control include first and foremost communication to create a common understanding of AMR and the need for rational AMU to limit the risk of AMR emerging. Open questions to investigate the other party’s current perception of AMR and rational AMU might be useful in this instance. Furthermore, the learning style of the farmer and/or veterinarian should guide the communication tools used to create a common platform of understanding. For example, practical illustrations of AMR in locally relevant situations can be used to make AMR comprehensible to some farmers, whereas theoretical explanations or reflections with peers (e.g. in a Stable School setting) will be beneficial for other farmers. Likewise, farmers might make use of similar communication tools if they disagree with the AMU practices of a veterinarian participating in their VHHC collaboration.

Throughout this process, it is important that the practising veterinarian clearly communicates when he or she may need to take on an authoritarian role, i.e. the “police officer”, with the purpose of immediately correcting any particularly bad AMU actions, so that he or she may return to the reflective process within the role of advising veterinarian as smoothly as possible. This should be done to avoid issues regarding “benevolence”, i.e. the veterinarian should be able to maintain the farmer’s trust in his or her benign motives in the VHHC and AMU change processes initiated, despite having AMU control obligations. As such, it should be clear to the farmer that the “police officer” and advising veterinarian are two parallel roles, and that the “police officer” role might be decoupled from the veterinarians’ personal motives and intentions within the VHHC.

Once an understanding of AMR and the need for rational AMU has been established – thus providing incentive and motivation for changing AMU – the veterinarian and the farmer can move towards the goalsetting and planning phase, in which self-determination and the involvement of all actors are crucial. Ways to reduce or refine AMU should then be discussed and a farmer and farm-specific plan should be agreed and the responsible parties identified. This plan includes ways to continuously follow-up whether rational AMU has been achieved, i.e. through appropriate qualitative and quantitative methods according to the purpose of the AMU change. Specific actions to achieve rational AMU could include specific interventions that are planned and executed during relatively stable times. For example, a farm might have issues with udder diseases and a high SCC. For that reason, the farmer and veterinarian might decide to test the use of teat sealers at dry-off for a certain amount of time, expecting the use of teat sealers to reduce the frequency of mastitis cases and thus the treatment frequency. Throughout that period, the intervention effect must be properly monitored so that the intervention can be halted if the effect appears to be negative. State space models can be used for that purpose. However, this would require that state space models are integrated as part of e.g. management programmes available to advisors and farmers, and that training and supervision on how to interpret the models are made available.

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9 Manuscripts

Manuscript I

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Manuscript II

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Manuscript III

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Manuscript IV

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Manuscript V

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9.1 Manuscript I

Veterinary herd health consultancy and antimicrobial use in dairy herds

Nanna K. Skjølstrup,[1*] Liza R. Nielsen,[1] Carsten S. Jensen,[2] Dorte B. Lastein[1]

[1]Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, 1870 Frederiksberg C, Denmark
[2]Department of Sociology, Faculty of Social Sciences, University of Copenhagen, 1353 Copenhagen, Denmark

*Corresponding author: Nanna K. Skjølstrup, Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, Grønnegårdsvej 2, DK-1870 Frederiksberg C, Denmark. Email: nannaks@sund.ku.dk.

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Abstract

The globally increasing level of antimicrobial resistance affects both human and animal health, why it is necessary to identify ways to change our current use of antimicrobials. The veterinary herd health collaboration between veterinarians and dairy farmers provides a useful setting for changing antimicrobial use in livestock. However, farmers and veterinarians work in a complex agricultural setting influenced by socio-economic factors, which complicates their choices regarding antimicrobial usage. It is therefore necessary to be aware of the range of potential influencing factors and to integrate this knowledge in the relevant local settings. This manuscript presents a literature review of relevant factors relating to antimicrobial use within the veterinary herd health consultancy setting, including knowledge gaps of relevance for changing the use of antimicrobials. An enriched version of the framework of the Theory of Planned Behaviour was used to organise the literature review. We identified diverging attitudes on correct treatment practices and perceptions of antimicrobial resistance among veterinarians and farmers, influenced by individual risk perception as well as social norms. Furthermore, disagreements in terms of goal setting and in the frequency of herd visits in relation to herd health consultancy can negatively influence the collaboration and the intention to change antimicrobial use. Farmers and veterinarians emphasise the importance of legislation and the role of the dairy industry in changing antimicrobial use, but the relevance of specific factors depends on the country-specific context. Overall, farmers and veterinarians must communicate better to understand each other's perspectives and establish common goals within the collaboration if they are to work efficiently to reduce antimicrobial use. Farmers and veterinarians both requested changes in individual behaviour; however, they also called for national and structural solutions in terms of balanced legislation and the availability of better diagnostics to facilitate a change in antimicrobial use practices. These various paths to achieving the desired changes in antimicrobial use illustrate the need to bridge methodological research approaches of veterinary science and social sciences for a better understanding of our potential to change antimicrobial use within the dairy farm animal sector.

Key words: antimicrobial use, antimicrobial resistance, veterinarians, farmers, veterinary herd health consultancy, decision-making, social factors, dairy cattle

Introduction

Antimicrobial use (AMU) is important to consider as antimicrobial resistance (AMR) is increasing globally, affecting both human and animal health (Tang et al., 2017; Laxminarayan et al., 2013). Within the farm animal sector, veterinarians are responsible for the use of antimicrobials in collaboration with the farmer. This specific interaction should therefore be taken into account when promoting "rational AMU", which here is defined as a limitation in inappropriate use, as well as a reduction in the need for antimicrobials. This definition has been adapted from the European Commission, which characterises inappropriate use as "use in an untargeted manner, at sub-therapeutic doses, repeatedly, or for inappropriate periods of time" (European Commission, 2015, 299/10). With this in mind, the veterinary herd health consultancy (VHHC), which frames the collaborative work between the veterinarian and the farmer at dairy farms around the world, comprises an interesting study case with regard to promoting rational AMU. The majority of antimicrobials currently used in dairy cattle are used to treat and control mastitis (Krömker and Leimbach, 2017, 22–23) and pneumonia in calves (Carmo et al., 2018a, 5–6), and these diseases are therefore central topics in the work on rational AMU.

Over time, veterinary tasks in dairy herds have changed character. Previously, the focus was primarily on the treatment and prescription of medicine, but there has more recently been a shift towards disease prevention (Woods, 2013; Bonnaud and Fortané, 2020, 11–16). With the introduction of epidemiology into veterinary science, the collection and analysis of quantitative data in veterinary practices has led to an acknowledgement that production diseases are multifactorial and connected with housing, nutrition, genetics, and other diseases. The concept of herd health management (HHM) was introduced and characterised as "an integrated, holistic, proactive, data-based, and economically framed approach to prevention of disease and enhancement of performance" by LeBlanc et al. (2006, 1267). The HHM approach and research within the area have inspired practitioners globally to introduce, advise on and apply preventive measures related to herd-level health and production, often through data- and knowledge-driven engagement on farms (Nir, 2003; Enevoldsen, 1997; da Silva et al., 2006). The HHM approach ideally implies a continuous collaboration between the farmer and the veterinarian, as the same veterinarian will often be affiliated with a farm over long periods of time. This close collaboration, in combination with a focus on herd health and production, provides a suitable setting for working explicitly towards rational AMU. The specific HHM approach differs from country to country (Fortané, 2020; Ruston et al., 2016; Woods, 2013; Enevoldsen, 1997), but the type of VHHC in focus in this review article is defined by a continuous collaboration between a farmer and the same veterinarian, with regular herd visits and a focus on herd health and production.

Research shows that the traditional focus on quantitative data analysis and economics embedded within the HHM approach does not motivate all farmers to change their behaviour (Andersen and Enevoldsen, 2004; Kristensen and Jakobsen, 2011; Lam et al., 2011; Garforth, 2015), and factors relating to farmers' and veterinarians' decision-making processes in particular need further investigation (Bokma et al., 2018; Wu, 2018). Farmers and veterinarians act in a complex agricultural context characterised by legislation on AMU, changing incomes due to fluctuating milk prices, the physical condition of the farm, farm and veterinary businesses aiming to make a profit, and social norms to which farmers and veterinarians try to adhere. All of these factors could potentially affect the choice to use antimicrobials rationally, implying the need to understand and take such "qualitative" factors into consideration as a part of the VHHC when working to change behaviour.

We argue that the choices made by farmers and/or veterinarians either individually or in collaboration, for example whether or not to prescribe or treat an animal, are the starting point for working towards rational AMU in dairy cattle. Our focus is therefore on the factors that influence behaviour in terms of rational AMU within farmers' and veterinarians' collaborative framework. Possible influencing factors affecting individual and/or collaborative AMU choices must be identified and considered from an overall sociological perspective. The VHHC could then not only be expanded to include quantitative data on health, production and economics as part of a motivation for change, but it could also be broadened to take farmer- and veterinarian-specific motivational factors into consideration.

However, not all factors are equally important to every farmer and veterinarian. Each farmer is a unique individual, and a personal approach should be taken within a specific-herd context (Ritter et al., 2017, 3330; Lam et al., 2011, 13). Furthermore, the local agricultural setting differs from country to country, which is why identified factors might not all be of equal importance across all countries. It is therefore necessary to relate every identified factor to the country of interest, with its national context-specific barriers and opportunities (Murphy et al., 2017, 160–61).

The overall objective of this study was to improve the understanding of relevant factors for achieving rational AMU within the collaborative context of VHHC in dairy cattle herds. The first sub objective was to review, summarise and discuss the factors of relevance for VHHC and rational AMU in dairy herds. Furthermore, the findings are discussed from a socio-economic perspective to broaden the understanding of their meaning. The second sub objective was to identify knowledge gaps of relevance for changing AMU practices within the VHHC setting, as well as challenges and opportunities for future research.

The initial inclusion criterion for the literature search was studies on dairy cattle and AMU (other types of medication were excluded). Secondly, studies had to be conducted in an intensive production context characterised by high milk production and relation to a global market, as we argue that there are different AMU-related factors at play in intensive and extensive farming. Finally, studies had to place an emphasis on the farmer-veterinarian relationship. The review began with a systematic literature search across seven databases, and 39 out of 122 articles were used in this review after screening for relevance. We also included additional articles conducted within the social science research field in order to discuss and elaborate on the multifaceted area of AMR research.

Overview of factors affecting the intention to move towards rational antimicrobial use: a socio-ecological model

Numerous factors influencing the intention to change AMU were identified in the literature search. We used a model developed and previously used in the disease prevention and control context as a structural framework to organise these factors and to give a better overview (Ellis-Iversen et al., 2010, 278). Their model was originally built upon a study by Panter-Brick et al. (2006, 2813) and was developed to illustrate barriers to the control of zoonotic diseases. Controlling zoonotic diseases is complex and unpredictable aspects must be taken into consideration, such as future consequences that can be difficult to comprehend and react on in the present, as is the case with AMR. The model was chosen due to its more holistic approach, taking into account the agricultural setting.

The model proposes that a person's intention to perform a certain behaviour can be explained by three factors: 1) the person's attitude, 2) the person's subjective norm and 3) the person's perceived behavioural control (Ajzen, 1991, 179–82). The original model builds on the Theory of Planned Behaviour, but has been further developed here in order to take extrinsic (e.g. national, regional and herd-specific) factors more directly into account (Panter-Brick et al., 2006, 2811–12). Panter-Brick et al. (2006) argued that intention to change is not driven solely by intrinsic factors, making the model socio-ecological and combining social and physical aspects of the individual. In our case, the relationship between two groups of individuals (farmers and veterinarians) and their cooperation within VHHC in the agricultural context is important. Therefore, we further developed the model to contain and organise the intrinsic and extrinsic factors while allowing for the factors to be either specific to one group or common to both.

The original Theory of Planned Behaviour and its focus on individual behaviour has been criticised on a number of occasions, especially in relation to its behaviourist foundation (Chandler, 2019, 5–10; Rynkiewich, 2020, 3; Broom et al., 2020, 1–3). In this context, we do not use the model as an argument for behaviourism but as a framework for structuring the research of different empirical aspects and contexts where the farmer-veterinarian interaction can influence the use of antimicrobials. The model helps us present an overview of areas and situations that influence AMU, both at individual and farm level, but also from a broader societal perspective. This is in line with research within the social sciences, where the structural dimensions related to AMU (e.g. social, economic and biological factors) are investigated (Chandler, 2019, 8–10; Denyer Willis and Chandler, 2019, 2).

The intrinsic factors in the model consist of three groups: 1) Behavioural beliefs representing a person's attitudes, which are often defined by core values, 2) Normative beliefs defined by social norms and how the individual perceives these, and 3) Belief in self-efficacy, which is closely related to a person's trust in their own ability to carry out the change.

The extrinsic factors also consist of three groups: 1) Community & Industry, including influence from the agricultural industry and trade partners as well as the rural community, 2) Culture & Society, including national legislation and guidelines as well as influence from consumers, and 3) Knowledge, Skills & Ability, relating to the overall availability of important resources, finances, knowledge and tools for possible change (Ellis-Iversen et al., 2010).

Figure 1 shows how the findings from the reviewed papers have been embedded in the model. The identified factors appear as headlines placed within the appropriate section of the model, e.g. concerning either one of the groups within the intrinsic or extrinsic factors, and relevant to either the farmer, the veterinarian or both. For each headline, e.g. "Responsibility placing", several studies may have contributed findings to support the importance of this factor. In the next section, the identified factors and the related literature are presented according to the structure of the model, starting with the intrinsic factors and ending with the extrinsic factors. It is important to note that only factors that were identified in the literature are summarised and discussed.

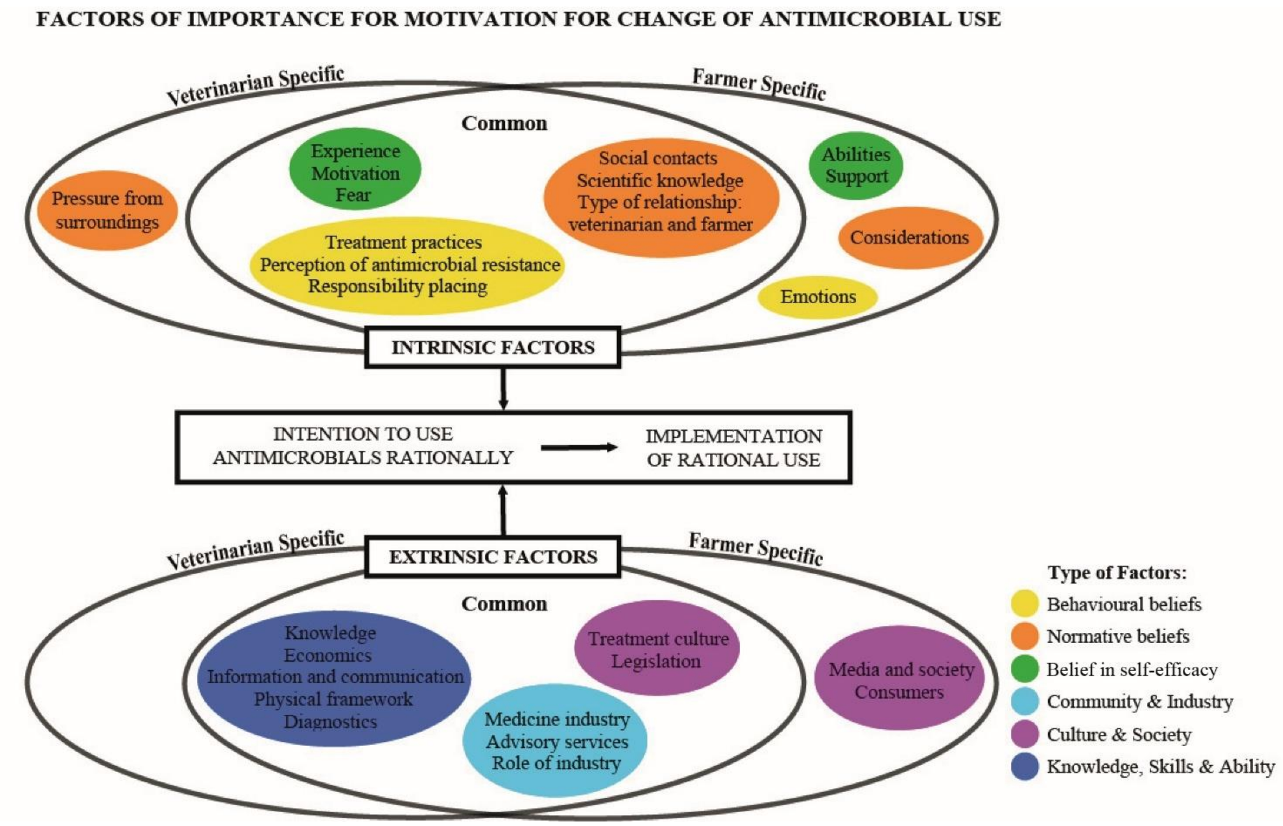

Figure 1: Factors influencing AMU. Some factors have been identified as common to both veterinarians and farmers, whereas others are only identified for the one or the other. The model was inspired by Ellis-Iversen et al. (2010).

Intrinsic factors affecting the intention to move towards rational antimicrobial use

Research on intrinsic factors related to an individual's attitudes, core values, perception of social norms and belief in their own ability to change will be presented in the following sections.

Differences in veterinarian and farmer attitudes on antimicrobial use

The first of the intrinsic factors are behavioural belief-based factors, concerning personal attitudes. The first point to be presented here, "Treatment practices" (Figure 1, intrinsic, common factor), appeared to be an important point for both veterinarians and farmers, with a range of attitudes on how to approach treatment. Several studies suggest that veterinarians and farmers both agree that sick animals need treatment (Speksnijder et al., 2015a, 44–45; McDougall et al., 2017, 86; Ekakoro et al., 2018, 4; Golding et al., 2019, 7), yet motives seem to differ between the two groups. According to Speksnijder et al. (2015a, 44), veterinarians regard diseased animals from a professional and ethical point of view, with treatment primarily related to their perceived obligation as a veterinarian to ensure animal health and welfare. For farmers, treatment appears to be driven by a focus on animal welfare and an urge to stop individual animal suffering (Vaarst et al., 2003, 112–13). However, the threshold for treatment can change, e.g. alleviating suffering among diseased animals can be addressed by intense follow-up instead of immediate treatment (Vaarst et al., 2006, 1845–47). Both studies identified practical farmer-specific issues related to having sick animals: it is time-consuming and interrupts the daily routine, and it can be economically challenging (Vaarst et al., 2003, 114; 2006, 1845–48). Having sick animals is therefore a complex issue for both farmers and veterinarians, but it complicates different aspects for the two groups. For veterinarians, it is mostly about ethical and professional standards, whereas for farmers, the challenges are primarily related to practical issues and emotional frustration.

Other perceptions about "Treatment practices" have also been identified in the literature (Figure 1, intrinsic, common factor). Several studies found that both veterinarians and farmers believe that vaccination plays a key role in reducing AMU (Golding et al., 2019, 11; Ekakoro et al., 2018, 7; Magalhães-Sant Ana et al., 2017, 5–7; Raymond et al., 2006, 3232–37). However, vaccination was perceived as ineffective among farmers in Washington State (Raymond et al., 2006, 3234). Differences in prescribing behaviour and AMU patterns have also been described. Misuse and illegal over-the-border purchases of antimicrobials have been identified among farmers (Raymond et al., 2006, 3233–34; Buller et al., 2015, 56; Cattaneo et al., 2009, 3496; Pucken et al., 2019, 9–10), and veterinarians from France, the UK and Switzerland expressed their frustration with veterinary prescribing behaviour, either directed at themselves or their colleagues (Poizat et al., 2017, 67; Golding et al., 2019, 9–12; Pucken et al., 2019, 8–10). Alternative treatment methods were perceived by farmers as being too time-consuming (Vaarst et al., 2003, 114–16; 2006, 1845), and a distrust in their effect was also identified (Vaarst et al., 2003, 115). The attitudes behind or reasons for some of these treatment practices cannot always be elaborated upon due to the study design that is traditionally used within veterinary research, e.g. surveys and questionnaires. For example, the position on vaccination among farmers in Washington State was identified based on a questionnaire study (Raymond et al., 2006), and this type of study rarely provides the reason behind an answer, as would be possible in an interview, for instance.

Looking into the social science literature from human medicine might provide some possible explanations for the identified treatment practices among veterinarians and farmers. For example, Broom et al. (2017, 1995) found a ritualised AMU among doctors. Specific treatments repeatedly resulting in positive outcomes might lead to both farmers and veterinarians believing that this treatment is more effective and therefore preferred. For the farmer, this might result in a request for specific antimicrobials, which he or she perceives as most effective. This could cause potential conflicts between veterinarians and farmers due to disagreements over drug preferences. Similarly, veterinary drug choices may be ritualised.

Responsibility for the rational use of antimicrobials and where this responsibility should be placed has also been studied (Figure 1, intrinsic, common factor, "Responsibility placing"). There is evidence in the literature that both farmers and veterinarians might perform "other-blaming" behaviour when placing responsibility for the rational use of antimicrobials. “Other-blaming” can be understood as viewing other people as responsible for causing an issue, while the individual’s own behaviour is perceived as unproblematic. One study from the UK found that frustrations among farmers and veterinarians due to the physical framework of the livestock industry as well as a lack of stewardship among doctors contributed to other-blaming (Golding et al., 2019, 7–12). The same finding was reported in the Netherlands, where the misuse of antimicrobials by doctors and international traffic were seen as the primary causes of AMR by some interviewed veterinarians (Speksnijder et al., 2015a, 45). Dairy farmers interviewed in Tennessee believed that there was no connection between AMU in agriculture and public health risks. Instead, this risk was perceived as being linked to AMU in the human sector (Ekakoro et al., 2018, 7). Renunciation of responsibility by both veterinarians and farmers can therefore act as a barrier to changing AMU.

In connection with this attitude and “Perception of AMR”, (Figure 1, intrinsic, common factor), some literature suggests that farmers and veterinarians perceive their own AMU as an insignificant contributor to global AMR (McDougall et al., 2017, 87; Speksnijder et al., 2015a, 44–45). However, the opposite opinion was also identified (Postma et al., 2016, 4; Speksnijder et al., 2015a, 44; Raymond et al., 2006, 3235), as well as an experience-dependant factor as more experienced veterinarians seem to be less aware of the potential risks related to antimicrobial overuse (Speksnijder et al., 2015b, 367). A survey completed by veterinarians from New Zealand found that younger veterinarians were more likely than older ones to perceive AMR as a risk (McDougall et al., 2017, 88). An ethnographic study conducted at a dairy farm in the UK concluded that the perception of AMR as a risk is related to knowledge. The study argues that knowledge of AMR within agriculture is based to large extent on practical experiences in specific farm contexts. Due to microbial culturing not being used at farm level, other factors will often outweigh resistance as plausible explanations for treatment failure (Helliwell et al., 2019, 1–9). To elaborate on the risk perception of AMR experienced by farmers and veterinarians, inspiration can be found in research conducted within human medicine. Doctors must balance the acute risk of losing a patient in need of antimicrobial treatment and the global, long-term risk of AMR (Broom et al., 2016, 828–30). Similarly, this could be an underlying mechanism explaining why farmers and veterinarians do not see their own AMU as a significant contributor to AMR globally; perhaps the acute risk of losing an animal takes priority over the long-term perspective of AMR, thus “forcing” the farmer or veterinarian to ignore the risk of resistance. In a similar way to the renunciation of responsibility mentioned above, the perception of own AMU as an insignificant contributor to global AMR can lower the intention to change AMU (Helliwell et al., 2019, 1–9).

Literature suggests that “Emotions” can shape farmers’ attitudes (Figure 1, intrinsic, farmer factor). Fischer et al. (2019, 2729) found that farmers felt frustrated when they had sick animals, and Vaarst et al. (2003, 113) found that “favourite cows” could receive treatment even when the prognosis was poor. This point about emotions was not found for veterinarians in the literature. Research on the prescribing behaviour of doctors identified the need to “just do something” when patients were close to dying (Broom et al., 2017, 1999). This feeling of at least trying to do something might be similar to the one experienced by farmers – and is potentially also evident for veterinarians.

As illustrated by the behavioural belief-based factors identified in the literature, farmers and veterinarians have different opinions regarding AMU and AMR. They differ in their understanding of AMR and the responsibility associated with it. Working collaboratively within a VHHC situation, potential challenges might occur due to disagreements or a lack of understanding of other people's perspectives. Having different core values regarding the motives for treatment might result in different treatment thresholds among farmers and veterinarians, with potential differences in the decision-making process and preferred solutions. Reasons for this have been discussed in the literature (Bonnaud and Fortané, 2020, 14–16), and economic models propose that people choose to act based on the maximum expected utility. However, this is not always the case as there is evidence that farmers do not always decide whether to treat an animal based on economic reasoning (Garforth, 2015).

It has also been suggested that decision-making is affected by the context, as well as ways of perceiving risk (Pindyck and Rubinfeld, 2013, 159–99). A difference in perception of risk among farmers and veterinarians has been proposed (Kristensen and Jakobsen, 2011, 2–4). Sorge et al. (2010, 1497–99) suggested that this difference may be due to the lack of knowledge among farmers affecting their risk perception, in this case relating to Johne's disease. In the case of AMR, it could be that farmers do not perceive AMR as a risk due to a lack of knowledge of local, global and future consequences. The knowledge deficit model describes how a poor understanding of the scientific reasoning behind any given advice is why lay people may not follow the advice. In other words, the reason for the difference in risk perception and decision-making between the veterinarian (the expert) and the farmer (the lay person) is due to the farmer's lack of knowledge (Hansen et al., 2003, 112). However, critics of the knowledge deficit model argue that risk assessment is complex and individual, and related to more than just a lack of knowledge (Hansen et al., 2003; Kristensen and Jakobsen, 2011, 3–6). Differences in risk perception due to a lack of knowledge is therefore not likely to be the sole explanation for the differences in attitudes between veterinarians and farmers. Instead, to avoid major disagreements jeopardising the collaboration within VHHC, farmer-specific VHHC have been proposed, where the individual farmer's risk perception and attitudes are explored through dialogue and taken into account (Kristensen and Jakobsen, 2011, 3–6).

In conclusion, the behavioural belief-based factors identified in this section highlight the importance of trying to understand the other party's perspectives and contextual framework, e.g. emotions, individual risk perception and attitudes, in order to avoid major disagreements that could jeopardise the ability to change AMU behaviour in collaborations between the farmer and the consulting veterinarian.

Social norms affecting the veterinary herd health consultancy relationship

Personal beliefs and attitudes contribute to a person's actions related to changing AMU, but these factors are also influenced by other people. The opinions and behaviour of others can influence and modulate a person's response by building "social norms", which are created as informal guidelines for behaviour within a group. Social norms are enforced through social sanctions, whereby people feel uncomfortable violating norms due to public disapproval possibly causing shame or embarrassment. Alternatively, following social norms can result in reputational benefit and improve one's self-concept (Sunstein, 1996, 914–25; Coent et al., 2018, 3–5). The literature suggests that the relationship with and opinions of other people are important to both farmers and veterinarians in terms of how their social norms are formed over time (Swinkels et al., 2015, 2375–79; Golding et al., 2019, 8–9). Some social associations are more relevant to veterinarians, some are more relevant to farmers, and some are relevant to both. The identified factors related to social norms affecting herd health management and AMU will be summarised according to this division and discussed in the following sections.

Social norms of the veterinarian

"Social contacts" (Figure 1, intrinsic, common factor) is a factor common to both farmers and veterinarians, but has a different meaning to each group (see below). For veterinarians, colleagues' opinions were identified as particularly important. A lack of support from colleagues over their choice of prescription could lead veterinarians to prescribe against their own judgement (Golding et al., 2019, 9). Swiss veterinarians attending peer study groups emphasised the importance of sharing their experience with their peers to gain new knowledge, compare themselves with others and receive new stimuli (Pucken et al., 2019, 12). It can be argued that veterinarians compare themselves with their peers and follow e.g. practice policies and their colleagues' prescribing choices in order to stay in line with social norms.

Another point from the figure with specific relevance to the social norms of the veterinarian is "Pressure from surroundings" (Figure 1, intrinsic, veterinarian factor). One aspect of this will be described here, the other in section 3.2.3 as it concerns the farmer-veterinarian relationship directly. As is apparent from the literature, colleagues' opinions are not always perceived positively but rather as a pressure to prescribe in a specific way. A practice policy for AMU was found to be an important factor for prescribing among veterinarians in New Zealand, next after their own training and costs/benefits for the farmer (McDougall et al., 2017, 88). This may imply that veterinarians do not want to go against or question an existing practice policy in some situations, so they choose to prescribe according to the policy and perhaps against their own judgement. A certain "prescribing etiquette" has been identified within human medicine, i.e. a set of cultural rules defining AMU. These rules are derived from a hospital culture where the autonomous and experience-based prescribing behaviour of senior doctors affects junior doctors. Furthermore, a culture of "non-interference" in colleagues' prescribing choices also exists (Charani et al., 2013, 190–94). Another study within human medicine identified certain "rules of the game" for AMU at hospitals. These rules arise due to the prescribing norms and working conditions at hospitals (Broom et al., 2014, 83–87). A prescribing etiquette and cultural rules for AMU might also apply to veterinarians. Despite veterinarians working more independently compared to doctors in a hospital setting, AMU choices might still be influenced by colleagues' opinions, as evident from the literature.

Social norms of the farmer

In relation to farmers, "Social contacts" (Figure 1, intrinsic, common factor) including opinions from a perceived positive reference group – namely other farmers – were identified as important (Swinkels et al., 2015, 2375–79). The concept of being "a good farmer" was introduced in connection with this, meaning the importance of living up to other farmers' perceptions of "good farming" (Swinkels et al., 2015; Fischer et al., 2019). The role of being "a good farmer" encompasses multiple social norms, each of them dictating appropriate behaviour (Burton, 2004, 207–10; Sutherland and Darnhofer, 2012). As identified in the literature, being "a good farmer" can imply achieving high production levels (Fischer et al., 2019, 2729) as well as using extended therapy for mastitis, i.e. treating for more days than recommended by the veterinarian in order to achieve the best possible treatment outcomes (Swinkels et al., 2015, 2374). Several studies have illustrated that "the good farmer" can have multiple meanings according to the local "rules of the game" (Sutherland and Darnhofer, 2012; Shortall et al., 2018, 589–99).

A local understanding of "the good farmer" could be established through communication with other farmers and through opinions from trusted sources, e.g. the veterinarian (Swinkels et al., 2015, 2376–77). In relation to this, it seems relevant to present the concept of "roadside farming". According to Burton (2004, 201–6), "Roadside farming" is characterised by the exchange of social information by farmers. This happens either by presenting their own farm as well as possible by the roadside or by evaluating other farms. Therefore, a local understanding of "the good farmer" might also be established through non-verbal communication, e.g. through "roadside farming". In conclusion, it is important for farmers to live up to their social contacts' perception of "good farming". The social norms related to this concept are created through communication (both verbal and non-verbal) with the outside world, and farmers probably choose to live up to the social norms due to an expected reputational benefit.

A second point specific to farmers is "Considerations" (Figure 1, intrinsic, farmer factor). The literature suggests that farmers perceive expectations from the dairy industry regarding rational AMU positively and as something they want to live up to (Jones et al., 2015, 34–37; van Dijk et al., 2017, 477). From a normative perspective, this could be explained as an aspect of being "a good farmer". Furthermore, farmers might be motivated to live up to expectations from the dairy industry if they expect to achieve a reputational benefit from doing so.

Social norms of the farmer-veterinarian interaction

One of the factors related to the farmer-veterinarian relationship is actually specific to veterinarians, but also directly relevant to the interaction between the two (Figure 1, intrinsic, veterinarian factor, "Pressure from surroundings"). The aspect related to colleagues has been described in section 3.2.1, but the aspect related to the farmer will be described here. The literature suggests that veterinarians experience pressure from their clients, and one of the reasons behind this has been identified as an actual or perceived client demand for antimicrobials (Gibbons et al., 2013, 2; Speksnijder et al., 2015a, 44; 2015b, 367; Espetvedt et al., 2013, 82–83; Postma et al., 2016, 4). Another reason for this pressure to prescribe antimicrobials is due to economic considerations for the farmers. Some broad-spectrum antimicrobials are economically attractive to farmers due to the short withdrawal periods, resulting in veterinarians experiencing pressure to prescribe in a less responsible manner – for example the cheapest treatment solution instead of the most suitable product (Golding et al., 2019, 8; McDougall et al., 2017, 86–87). Social norms might also explain why veterinarians feel a pressure to prescribe; they may experience social sanctions (e.g. a bad reputation) from the farmer if they refuse to prescribe cheap broad-spectrum antimicrobials. Research within human medicine has shown that local norms for prescribing practices and interpersonal pressure from patients and their relatives, together with the risk of patients relapsing when not treated, influenced AMU at hospitals (Broom et al., 2016, s. 830-834). Similar social and cultural influences might be at play in the veterinarian-farmer collaboration, perhaps encouraging the veterinarian to prescribe out of consideration for the continued relationship with the farmer, the risk for the animal, or an urge to comply with social norms. There seems to be a disparity between what veterinarians and farmers perceive as the "correct" choice of antimicrobials and the parameters that this choice should be based on. This disparity could cause complications in the VHHC collaboration, and a mutual understanding should therefore be sought and choices related to AMU should preferably be based on scientifically valid general or local evidence (Lastein, 2012).

"Scientific knowledge" has been identified as an important guide of both veterinarians' and farmers' behaviour (Figure 1, intrinsic, common factor). However, there is a difference in the perception of "scientific knowledge": farmers primarily view the veterinarian as a representative of scientific knowledge (Kramer et al., 2017, 147), whereas published literature from veterinary experts is the epitome of "scientific knowledge" for veterinarians themselves (De Briyne et al., 2013, 3; Postma et al., 2016, 4–5; Buller et al., 2015, 60). This difference in perception could also affect the veterinarian-farmer collaboration in relation to HHM. Farmers might not appreciate veterinary recommendations based on published literature, as they may find the advice incompatible with the reality on their farm and expect the veterinarian to adjust the advice accordingly (Bonnaud and Fortané, 2020, 15).

Regarding the "Type of relationship" between the veterinarian and the farmer within a VHHC setting (Figure 1, intrinsic, common factor), the literature suggests that both groups agree on the importance of a good collaboration when working with AMR (Golding et al., 2019, 11). A stable school project in Denmark showed that a mutual trust and openness among the participants had a significant influence on the results obtained (Vaarst et al., 2007, 2548–50). A study from the UK also highlighted the importance of established trust between the veterinarian and the farmer in terms of the veterinarian knowing the actual AMU on the farm (Buller et al., 2015, 58). A lack of commitment or understanding of the individual farmer's way of farming (e.g. organic farming) was found to negatively influence the relationship from the farmer's perspective (Vaarst et al., 2003, 113–14; Duval et al., 2017, 19–20). Conversely, veterinarians in France felt that they were stuck in a role as "firefighters" at organic farms and faced difficulties changing this role due to a lack of regular farm visits and farmers' lack of appreciation for advisory services (Duval et al., 2016, 12–18). Furthermore, some Flemish veterinarians believed that the farmers' mentality when it came to using antimicrobials led to high AMU, thus discouraging the collaborative effort (Postma et al., 2016, 2–3). The influence of farmers' mentality, behaviour, age and knowledge on veterinary prescribing behaviour was mentioned by Swiss veterinarians (Pucken et al., 2019, 8–9). Furthermore, veterinarians emphasise the importance of regular visits to work preventively to tackle disease instead of focusing on treatments (Magalhães-Sant Ana et al., 2017, 3–4; Speksnijder et al., 2015a, 42).

The perceived importance of the mutual relationship between both veterinarians and farmers might be explained by the concept of trust (Ruston et al., 2016, 89). Möllering (2001, 4) gave definitions of trust in the following statement: "Trust can be defined, first of all, as a state of favourable expectation regarding other people's actions and intentions. As such it is seen as the basis for individual risk-taking behaviour, co-operation, reduced social complexity, order, social capital, and so on". Reduced social complexity implies that social interactions can proceed without the constant evaluation of potential actions by those involved (Luhmann, 2017, 5–35). By establishing trust within the relationship, veterinarians and farmers can reduce the complexity of their social interaction and need not discuss or evaluate every single outcome of a certain decision.

According to Luhmann (2017, 21–26), we are more trusting of a familiar person than a stranger, and establishing a relationship takes time, which may explain why some interviewed veterinarians from Ireland and the Netherlands emphasised the importance of regular herd visits. Luhmann (2017, 21–26) also mentions how trust is less likely to be broken within a persistent relationship, such as the relationship between a veterinarian and a farmer, who will most likely have to continue their collaboration over an undefined period of time. When farmers experience a lack of understanding and commitment from their veterinarian, they may also experience a lack of trust. According to Luhmann (2017, 21–26), no one wants to take too many risks when initially building up trust within a relationship. This could explain the farmers' mentality negatively affecting the collaboration, as experienced by the Flemish veterinarians surveyed. Another example of these mechanisms can be found in a social science study concerned with VHHC from European countries and the USA, which identified a tendency for veterinarians to prefer farms with intensive farming due to the regular visits and the potential to build up a close relationship with the farmer. In contrast, relationships with farmers from extensive farms were more distant as they had diverging views on the need for consultancy and less regular herd visits, possibly implying a relationship built on less trust, commitment and understanding (Bonnaud and Fortané, 2020, 15).

In conclusion, both farmers and veterinarians care about other's opinions and these can influence their own opinions and behaviour. Within collaborations such as a VHHC agreement, both parties should be aware of the influence they have on each other. A better understanding of each other's perspectives, wishes and drivers can result in a more purposeful VHHC towards a local and practical rational AMU. In relation to this, building a mutual relationship through dialogue based on trust could reduce social complexity. A theoretical understanding of the mechanisms behind social norms and their impact on individual behaviour is also of importance.

Social norms shaping attitudes and behaviour

Some of the factors placed within the behavioural belief-based factors might also be explained by social norms. Different treatment practices might be a result of social norms developed within the local society of the farmer and the veterinary clinic. The concept of being "a good veterinarian" might be equally as relevant as "the good farmer", and also shaped by social norms. For example, social norms might explain why veterinarians see it as their duty to alleviate the suffering of animals, since years of education have taught them to do so. It has been proposed that norms are based on beliefs about facts. If new knowledge emerges and changes what is understood as correct, new norms might be created. However, these changes are often delayed due to the difficulties people face when changing norms and admitting the mistakes of former beliefs (Sunstein, 1996, 931). The pressure to prescribe experienced by veterinarians might be complicated further due to a potential delay when changing norms that leads to a disparity in beliefs and knowledge on rational AMU among both veterinarians and farmers.

For farmers, the misuse of antimicrobials identified by Raymond et al. and Buller et al. (2006, 3233–34; 2015, 56) in the previous section on behavioural belief-based factors can also be discussed from a social norm perspective. It has been proposed that some people simply like to violate social norms, also known as "flouting convention", which could explain the misuse of antimicrobials by farmers. Another perspective on the misuse of antimicrobials might be a disapproval of norms due to reflective judgement (Sunstein, 1996, 918). The surveyed farmers in the study by Raymond et al. might be dissatisfied with the legislation related to AMU and want to contribute to a new way of thinking and new social norms (2006). In connection with this, the theory of psychological reactance might also offer an explanation about the farmers' behaviour. If a person's perceived free behaviour is restrained, for example if a farmer is forced to use certain antimicrobials and these must always be prescribed by a veterinarian due to legislation, they may feel motivated to regain their freedom and use the antimicrobials illegally, ignoring the social influence from others (Steindl et al., 2015). It is possible that similar tendencies could be identified for veterinarians, e.g. a delayed response to regulations on the use of critical antimicrobials, we have, however, not found published literature describing such behaviour.

Summarising normative belief-based factors underlines the influence of social norms in the everyday work of veterinarians and farmers – both individually and in their collaboration. In addition, awareness of how social norms can influence and explain attitudes and decisions may help to improve mutual understanding within a VHHC setting.

Utilising the positive feedback loop of self-efficacy

This section concerns the third of the intrinsic factors, the belief in self-efficacy based factors. Belief in self-efficacy is a person's trust in their own ability to do something. Without this trust in oneself, it can be difficult to change behaviour. "Experience" seems to be an important aspect in achieving self-efficacy for both farmers and veterinarians (Figure 1, intrinsic, common factor). The literature suggests that for veterinarians, a lack of work experience can affect their trust in their own decisions (Speksnijder et al., 2015b, 367). Personal experience with specific drugs or treatments also affects veterinarians' decisions (Postma et al., 2016, 4; Gibbons et al., 2013, 2; McDougall et al., 2017, 86; Cattaneo et al., 2009, 3497–98; Pucken et al., 2019, 11). Similarly, personal experience also guides the drug choices doctors make at hospitals, where the clinical situation determines the use of antimicrobials independent of formal policy recommendations (Charani et al., 2013, 193). The literature suggests similar aspects among farmers, and several studies have identified a large amount of trust in their own treatment experiences (Friedman et al., 2007, 371–72) – sometimes they will trust this even more than the veterinarian's advice (Ekakoro et al., 2018, 6; Vaarst et al., 2003, 113–14; 2006, 1848–49; 2007, 2549; McDougall et al., 2017, 86). Some studies have identified the use of antimicrobials without any input from the veterinarian, which perhaps implies the same thing (Jones et al., 2015, 33–34; Kramer et al., 2017, 144). The opposite situation, where the veterinarian works as a trusted source of information for the farmer and possibly contributes to an improved belief in self-efficacy has also been identified, as previously mentioned (McDougall et al., 2017, 86; Fischer et al., 2019, 2732) (Figure 1, intrinsic, farmer factor, "Support").

Besides experience, "Fear" also affects the self-efficacy of both farmers and veterinarians (Figure 1, intrinsic, common factor). The fear of a negative implication on animal welfare if AMU is reduced further was identified for both groups (Buller et al., 2015, 55–56; Postma et al., 2016, 4; Golding et al., 2019, 7; Jones et al., 2015, 34). Some farmers also feared a decline in production, as identified in the survey by Jones et al. (2015, 34) and the interview study by Golding et al. (2019, 7), as well as economic losses in general. Furthermore, the literature suggests that some farmers are scared to change or halt their AMU due to the risk of relapse in their animals (Poizat et al., 2017, 64; Swinkels et al., 2015, 2373), indicating that emotions act as a barrier.

Fischer et al. (2019, 2731) identified a lack of ability among farm workers to identify sick animals (Figure 1, intrinsic, farmer factor, "Abilities"). The study also identified a sense of apathy among farmers due to external factors present on their farm, e.g. time and economic constraints sometimes making it difficult to deal with sick animals. A lack of ability and an apathetic attitude can further affect the self-efficacy of farmers.

There is uncertainty surrounding "Motivation" (Figure 1, intrinsic, common factor) for both farmers and veterinarians and how this affects their belief in self-efficacy. For example, the reason for farmers from the UK not wanting to change AMU on their farms after participating in workshops with a focus on the same is unknown (van Dijk et al., 2017, 480–83). However, as identified in a stable school project in Denmark, sharing good examples or solutions increased the motivation for change among farmers, probably because changing one's own practices seems more achievable when others have succeeded in making similar changes (Vaarst et al., 2007, 2549). The importance of seeing a positive effect of measures taken to improve AMU was identified among farmers. Seeing the results of successfully implemented measures increases the motivation to continue, possibly due to a higher level of trust in self-efficacy (Vaarst et al., 2006, 1844). The literature suggests that veterinarians' motivation is influenced by their clients' motivation (Speksnijder et al., 2015b, 368–71; Golding et al., 2019, 8), e.g. in a positive feedback. Again, there is an element of uncertainty involved – could a lack of motivation for veterinarians be due to a lack of belief in their own ability to affect the farmers' motivation?

According to Bandura (1999, 27–32), self-efficacy is an individual's belief that their effort will produce desired effects, affecting their motivation to act. If people truly believe that they have the ability to change something, they are more likely to try to do so. Bandura also highlights the effect of fulfilling valued goals, which results in self-satisfaction and increased motivation. This might explain why farmers' and veterinarians' motivation can be driven by a belief in self-efficacy via positive feedback. The identified fears of a negative impact on animal welfare and a decline in production might be connected to doubts about their ability to act according to their own core values within a restricted AMU setting. By being aware of the different barriers or opportunities for improving an individual's self-efficacy, veterinarians and farmers can better assist each other in increasing the motivation to act.

The following section will describe extrinsic factors that may have an effect on the intention to move towards a more rational AMU, as well as hinder or promote its implementation.

Extrinsic factors affecting the intention to move towards rational antimicrobial use

Extrinsic factors relating to the external framework surrounding the farmer and the veterinarian will be presented in the following sections. The extrinsic factors include three groups: Community & Industry; Culture & Society; Knowledge, Skills & Ability.

Agricultural industry and community influencing antimicrobial use on farms

Literature suggests that the rural industry (Figure 1, extrinsic, common factor, "Role of industry") plays an important role in the development of improved AMU for both farmers and veterinarians (Magalhães-Sant Ana et al., 2017, 3–4; van den Borne et al., 2017, 7–8; Carmo et al., 2018b, 6; Buller et al., 2015, 60–61; Fischer et al., 2019, 2732–33). According to Golding et al. (2019, 10), interviewed farmers expressed a need for the industries and the government to lead the development by supporting research, providing specific guidelines and ensuring better prices for farmers' products. However, which partner should take responsibility differs depending on the respondent, with retailers, food companies, national and international authorities, farm associations, the dairy industry and veterinary organisations all being mentioned (Magalhães-Sant Ana et al., 2017, 3–4; Golding et al., 2019, 10; van den Borne et al., 2017, 7–8; Buller et al., 2015, 60–61).

The "Medicine industry" (Figure 1, extrinsic, common factor) represents an important actor in the agriculture industry, and the literature suggests that both farmers and veterinarians are concerned about it in terms of changing AMU. However, ease of administration has primarily been identified as a consideration for veterinarians, whereas farmers are more focused on the price of medicines. For example, surveys completed by veterinarians from Ireland, the Netherlands, Flanders and other European countries indicated that veterinarians consider the ease of administration for both themselves and the farmer when choosing an antimicrobial drug (De Briyne et al., 2013, 3; Gibbons et al., 2013, 2–3; Postma et al., 2016, 4), while farmers complain about medicine prices and choose antimicrobial drugs based on withdrawal times (Poizat et al., 2017, 65; Jones et al., 2015, 33–34; Ekakoro et al., 2018, 5–6). In addition, some veterinarians from France requested more knowledge regarding alternative medicines (Poizat et al., 2017, 67), and farmers in a focus group study suggested improved labelling of drugs so that correct dosages, withdrawal times and the appropriate disease indication would appear clearly on the original label (Ekakoro et al., 2018, 9).

Another aspect of the rural community that both veterinarians and farmers believe influences their intention to change AMU is the "Advisory services" (Figure 1, extrinsic, common factor), which we will discuss in the context of HHM contracts between the two groups. The literature suggests that veterinarians focus on retaining clients, e.g. to ensure income (Speksnijder et al., 2015a, 42; Pucken et al., 2019, 11). Some veterinarians in the UK do so by making adjustments according to the farmer's economic situation or by compromising their own opinions to avoid conflicts and thereby maintaining client relationships (Golding et al., 2019, 8–9). Ohio veterinarians emphasised the importance of advisory services to reduce the need for antimicrobials (Cattaneo et al., 2009, 3497). From the farmers' perspective, some have expressed their frustration regarding prices for veterinary assistance and advice (Vaarst et al., 2003, 113–14; Raymond et al., 2006, 3237; Ekakoro et al., 2018, 6; Golding et al., 2019, 9). Other farmers believed consultancy was of limited benefit due to different goal setting or perspectives between themselves and the veterinarian (Vaarst et al., 2003, 113–14; 2007, 2549; 2006, 1848; Duval et al., 2016, 12–18; 2017, 19–20). Some farmers requested more frequent herd health consultancy from their veterinarian (Vaarst et al., 2003, 113), and a survey from the UK identified an association between a positive opinion of herd health plans and a high level of knowledge of AMR among farmers (Higham et al., 2018, 6).

As indicated by the summarised factors of importance relating to "Community & Industry", veterinarians and farmers are concerned with the same issues, e.g. the role of industry, the medicine industry and veterinary advisory services. However, their perspectives are not always aligned. The collaboration within VHHC can be complicated due to different interests, e.g. intervals between visits. Communication is needed to align expectations for the collaboration and to avoid veterinarians compromising to retain clients. Furthermore, communication could also result in a mutual understanding of what is important to each group, e.g. medicines that are cheaper or easier to administer, or industry- or government-led initiatives to reduce AMR. Not all of these needs should or could be fulfilled within the VHHC collaboration, but working towards a mutual understanding and establishing a common goal within the collaboration could create a sense of unity, which could subsequently promote positive feelings towards the collaboration in general.

The identified factors relating to the role of the industry, the medicine industry and advisory services will vary from country to country. It is relevant to consider different factors depending on the country's history regarding the introduction, development and role of advisory services, the medicinal products available on the national market, and the usual role played by the industry. Therefore, the factors must be carefully considered in relation to the context in question.

Legislation, consumers and culture influencing antimicrobial use on farms

In terms of "Culture & Society"-based factors, "Legislation" is an important factor for both farmers and veterinarians (Figure 1, extrinsic, common factor). In line with the role of the industry mentioned in the previous section, government initiatives to enforce rational AMU are called for in the international literature. Experts consulted in a study by Carmo et al. (2018b, 6) agreed that mandatory interventions have a high potential to reduce AMU. Several studies have identified a need for more legislation in the area of AMU (Magalhães-Sant Ana et al., 2017, 3; Poizat et al., 2017, 69; Fischer et al., 2019, 2732–33; Pucken et al., 2019, 10; Speksnijder et al., 2015a, 44–45; Postma et al., 2016, 6), but the opposite opinion was also identified in the literature (Kramer et al., 2017, 144–45; Postma et al., 2016, 6). Interviewed farmers from the UK expressed concerns about the administrative work and "tick-box" conformity following legislative initiatives (Buller et al., 2015, 61). In addition, some of the interviewed farmers felt that legislative restrictions on AMU challenged their economic situation and disrupted their business (Golding et al., 2019, 9–10). Swiss farmers and veterinarians stated that no penalty should be given to farmers with high AMU (van den Borne et al., 2017, 7). The different attitudes towards legislation and the role of the government might depend on the country in which the study was conducted. As illustrated by Postma et al. (2016), the surveyed veterinarians from the Netherlands and Flanders had differing opinions on governmental restrictions on AMU. This might be due to the different legislative history of the two countries. At the time of the study, the Netherlands had already experienced legislative restrictions on their AMU and had managed to reduce their AMU without compromising animal welfare, resulting in a more positive attitude towards governmental restrictions. In contrast, Flanders had not yet gone through these changes, possibly explaining their more sceptical attitude towards the possibility of reducing their AMU. A similar tendency was found in the study by Swinkels et al. (2015), who found that the interviewed dairy farmers from Germany and the Netherlands also had different opinions on governmental restrictions depending on their country's history and their production structure.

Two farmer-specific points were identified in the literature, namely "Consumers" and "Media and society" (Figure 1, extrinsic, farmer factor). Farmers perceive society as a negative reference group due to a lack of support and understanding of the dairy production process. Interviewed farmers from Sweden, Germany and the Netherlands expressed their frustrations about society due to a simplified and judgemental view of AMU in livestock production and a lack of appreciation of their work in food production in general (Swinkels et al., 2015, 2377–78; Fischer et al., 2019, 2732–33). The media is not perceived as a trusted source of information regarding AMR, and some farmers felt that it assisted in creating a skewed view of agriculture (Golding et al., 2019, 7; Fischer et al., 2019, 2732–33). Swedish farmers were also frustrated with the double standards among consumers regarding animal health and environmental issues (Fischer et al., 2019, 2732), and some farmers from Tennessee mentioned a lack of knowledge among consumers, causing misunderstandings about milk marketing (Ekakoro et al., 2018, 7–9). However, farmers from the UK also acknowledged the potential for consumers to drive an improvement in AMU by demanding certain product standards (Golding et al., 2019, 9–10). To our knowledge, concerns regarding consumers, media and society have not been identified for veterinarians within the literature. This might be due to the less direct effect on their profession, as opposed to the livestock industry, which instantly feels the economic consequences of a downturn in demand.

Within "Culture & Society", different treatment cultures were also identified in the literature (Figure 1, extrinsic, common factor). The factor "Treatment culture" is defined as treatment options that have been shaped by the respective country. This is exemplified by the questionnaire study by Espetvedt et al. (2013, 86), where Norwegian, Swedish, Finnish and Danish veterinarians were asked about their treatment thresholds for mild clinical mastitis. Differences in treatment thresholds across the four countries were identified and reasons behind this hypothesised, e.g. due to differences in pathogens, herd size and farming systems, distance between herds and country geography in general, as well as differences in penalties, herd health programmes and legislation. Treatment culture is not only valid for veterinarians, farmers too are affected by the situation in their specific country. For example, surveyed farmers from Tennessee requested treatment protocols to guide their AMU (Ekakoro et al., 2018, 10). Farmers from other areas of the United States also stated a need for protocols, but few actually used them (Raymond et al., 2006, 3231; Friedman et al., 2007, 373). The lack of treatment protocols or a reluctance to follow them as a part of farming culture could lead to unnecessary use of antimicrobials, thereby creating a country-specific treatment culture.

Looking into the VHHC collaboration, communication between the veterinarian and the farmer is important for achieving a mutual understanding of things that are perceived as important by each side, as seen with the “Community & Industry”-based factors. In terms of “Culture & Society”-based factors, this includes attitudes towards legislative restrictions and – specifically for the farmers – how consumers, media and society are perceived. Again, a mutual understanding and a common goal could create a sense of unity, which could give rise to a positive attitude towards the collaboration in general.

When comparing different countries in relation to AMU and factors of importance for changing AMU, it is important to be aware of the agricultural framework of the countries of interest. As previously stated in this section, treatment cultures seem to be dependent on the country in question, as well as legislation and the role of consumers and society in general. Therefore, it is important to contextualise for national conditions.

Availability of resources influencing antimicrobial use on farms

This section concerns the last of the extrinsic factors, the “Knowledge, Skills & Ability”-based factors. According to the literature, veterinarians and farmers agree on the overall importance of “Knowledge”, “Economics”, “Information and communication”, “Physical framework” and “Diagnostics” when addressing the resources available to support a change in AMU.

In terms of “Knowledge” (Figure 1, extrinsic, common factor), both groups are focused on further education as a key factor in changing AMU (Magalhães-Sant Ana et al., 2017, 4–5; Carmo et al., 2018b, 3–11; Cattaneo et al., 2009, 3496–97; De Briyne et al., 2013, 5; Gibbons et al., 2013, 4; Ekakoro et al., 2018, 7–11; Friedman et al., 2007, 373; Kramer et al., 2017, 144–47). Several studies have identified a lack of knowledge of AMR among farmers (Ekakoro et al., 2018, 7; Buller et al., 2015, 50–52; Higham et al., 2018, 6; Poizat et al., 2017, 67; Helliwell et al., 2019, 1–9), and younger veterinarians have been identified as being more knowledgeable about AMR compared to their older colleagues (Cattaneo et al., 2009, 3497). Furthermore, veterinarians focus on the need for research on AMR (De Briyne et al., 2013, 5–6; Magalhães-Sant Ana et al., 2017, 6).

Besides a lack of knowledge, the economic situation of the veterinary practice can influence the intention to change AMU for veterinarians (Figure 1, extrinsic, common factor, “Economics”), but this depends on the country-specific legislation and economic structure relevant to the veterinary practice. Veterinarians across all Nordic countries are only allowed to profit marginally from the sale of antimicrobials (Espetvedt et al., 2013). If a larger proportion of veterinary income could be derived from the sale of antimicrobials, this may lead to more frequent prescribing (Gibbons et al., 2013, 2–4). There was an association between years of work experience and an expressed need to retain the right to sell and earn money on antimicrobials among Dutch veterinarians (Speksnijder et al., 2015b, 367). However, in another Dutch study, interviewed veterinarians declared that pharmacy incomes did not drive antimicrobial prescription (Speksnijder et al., 2015a, 45). In France, the veterinary profession has been accused of contributing to the increasing AMR due to their professional conflict of interest as medicine sales make up a large proportion of their income. This led to them redefining the veterinary position in the public debate on AMR (Fortané, 2019, 3–7). Another aspect of "Economics" is the farmer's economic situation, which is often regarded as a limitation to changing AMU by both veterinarians and farmers (Golding et al., 2019, 8; Friedman et al., 2007, 373; Magalhães-Sant Ana et al., 2017, 3; Fischer et al., 2019, 2731; Speksnijder et al., 2015b, 368–71; 2015a; Postma et al., 2016, 2).

In line with the economic situation, the "Physical framework" of the farm often challenges change (Figure 1, extrinsic, common factor). The importance of good management (Ekakoro et al., 2018, 7; Vaarst et al., 2006, 1844–48; van Dijk et al., 2017, 481–82; Buller et al., 2015, 57), climate and housing conditions (Speksnijder et al., 2015b, 370; Postma et al., 2016, 2–3; Golding et al., 2019, 11), quality of feed (Speksnijder et al., 2015b, 368; Postma et al., 2016, 3) and biosecurity (Magalhães-Sant Ana et al., 2017, 5; Raymond et al., 2006, 3234; Postma et al., 2016, 2–3; Carmo et al., 2018b, 6–7) are all emphasised by both farmers and veterinarians. An ethnographic study conducted in East Africa concluded that antimicrobials often became a "quick fix" for a lack of hygiene among citizens (Denyer Willis and Chandler, 2019, 3–4). A similar tendency for antimicrobial misuse could be a consequence of poor hygiene at dairy farms. The literature suggests an apathetic attitude among farmers and veterinarians towards the physical framework at farms and the challenges this causes. This could imply a shifting focus from changing individual behaviour to an institutional focus as a prerequisite for change. Instead of farmers taking responsibility by renovating and improving their farm facilities and management, conditions for farming in general could be improved at a national level. Continuing to describe the factor "Physical framework", time constraints faced by farmers could challenge changes in AMU for both the farmers themselves and their affiliated veterinarian (Speksnijder et al., 2015b, 368; Golding et al., 2019, 9; Friedman et al., 2007, 373; Fischer et al., 2019, 2731; Poizat et al., 2017, 64). Furthermore, some veterinarians agree on the importance of reliable and accurate farm data on AMU and herd performance in evaluating farm-specific AMU and identifying areas for improvement (Speksnijder et al., 2015a, 42; Magalhães-Sant Ana et al., 2017, 4; Carmo et al., 2018b, 11), however, we did not identify the same focus from farmers within the included literature.

Literature suggests a mutual focus on the importance of communication skills when addressing AMU and AMR (Figure 1, extrinsic, common factor, "Information and communication"). A lack of communication skills (Golding et al., 2019, 14) and communication on the topic in general was highlighted by both veterinarians and farmers (Friedman et al., 2007, 370; Gibbons et al., 2013, 4; Cattaneo et al., 2009, 3496). Relevant stakeholders in Ireland have requested more information on AMR and for this to be communicated in an effective way (Magalhães-Sant Ana et al., 2017, 5).

Lastly, "Diagnostics" (Figure 1, extrinsic, common factor), including availability, prices and usefulness, leads to frustrations among both veterinarians and farmers. Interviewed farmers from New Zealand were not convinced of the usefulness of bacterial culture since their veterinarian's prescriptions were not affected by the results (McDougall et al., 2017, 86). Several studies identified limitations in the diagnostics available, e.g. due to costs, sampling difficulties, the time required, the variable and multiple pathogenic results and the veterinarians' own experience conflicting with the results (Speksnijder et al., 2015a, 43; De Briyne et al., 2013, 3; Golding et al., 2019, 8; Carmo et al., 2018b, 4; Helliwell et al., 2019, 6). However, the literature suggests that both veterinarians and farmers agree that valid diagnostics are important and should be implemented further (Magalhães-Sant Ana et al., 2017, 4–5; Ekakoro et al., 2018, 9; Raymond et al., 2006, 3236; De Briyne et al., 2013, 4; Golding et al., 2019, 8; Carmo et al., 2018b, 8–9).

Several "Knowledge, Skills & Ability"-based factors are therefore important when looking at the resources required to assist a change in AMU according to veterinarians and farmers, and both groups seem to be concerned about the same factors. However, communication remains important as the individual farmer or veterinarian might have different needs (Jansen et al., 2010, 1303–4). One could imagine a newly educated veterinarian being employed as the herd consultant at a farm with no history of using diagnostics in mastitis treatment. In this case, the veterinarian might not need knowledge of AMR. However, the veterinarian might perceive that the farmer lacks knowledge about both mastitis diagnostics and AMR. Only through communication and by striving to understand each other's perspectives can they agree on a plan that both parties accept.

As with the other identified factors, not all the "Knowledge, Skills & Ability"-based factors are of equal relevance across all countries. It is possible to imagine that there are different traditions in the use of diagnostics, physical frameworks of farming and the level of knowledge about AMR across different countries. Therefore, it is important to contextualise according to national conditions.

Changes in antimicrobial use from individual versus societal perspectives and future prospects

This review of relevant factors in the journey towards rational AMU in dairy cattle herds within a VHHC setting has shown that veterinarians and farmers emphasise more national-oriented solutions as well as those related to the local collaboration. Examples include the request for support from the dairy industry and sector organisations, as well as a revised VHHC framework. Additionally, there was a call for balanced legislation on AMU that will not compromise animal welfare or herd finances, and a new discourse on AMU in media and among consumers. These are all examples of areas in which national or structural solutions are demanded by farmers and/or veterinarians.

As mentioned in the introduction to the methodology used in this article (section 2), the focus on individual behavioural change as a way to reduce AMU, as embedded in the Theory of Planned Behaviour, has been criticised. Instead, there is an emphasis on the need to understand the structural dimensions related to AMU. However, the literature on which this review is based has illustrated that farmers and veterinarians call for both approaches. Due to the type of research, e.g. interview studies that take the individual farmer or veterinarian and their perspectives as a starting point, much of the included literature tends to focus on conclusions at the individual level. These individual solutions will be relevant in an everyday situation, as well as being the continual focus of the local VHHC. However, the factors mentioned by farmers and veterinarians in the included literature, which lie beyond the framework for individual action and in their opinion call for national and international solutions, underlines the need to elaborate the farmer-veterinarian collaboration and include and understand the relevant context. To study these elements, there is a need for a change in research methodology.

Researchers within the field of social sciences have used other methodological approaches to understand the field or the context surrounding AMU. They often take a societal starting point as opposed to an individual one by mapping e.g. the discourse (Chandler, 2019), actors and stakeholders (Fortané, 2019), social and biological processes (Hinchliffe et al., 2018), infrastructure (Denyer Willis and Chandler, 2019) and networks (Broom et al., 2014) relevant to AMU.

The approach in this article is reminiscent of a societal approach. We used a model that originally built on the Theory of Planned Behaviour as a structural framework to map all the relevant factors for farmers and veterinarians, and to outline the differences and potential challenges these differences can cause in the VHHC collaboration. However, it is clear from social science research within the area that the context includes more than just national differences in e.g. legislation, the economic model and daily tasks of veterinary practices, available diagnostics and medicines. It is also about discourse and connections between historical, economical and farming structure developments and social and biological processes (Landecker, 2016; Broom et al., 2020; Chandler, 2019; Hinchliffe et al., 2018). These structures and developments all become entangled in the individual veterinarian's or farmer's lifeworld, as well as in their mutual collaboration.

The literature that met the inclusion criteria of this review was primarily conducted within the veterinary research area. It investigates farmers' and veterinarians' perception of AMU and their possibility to change it within the VHHC setting. Analysis of the literature has clarified that there is more at play in the farmer-veterinarian collaboration than just economic and rational considerations. Social and cultural norms in the form of specific "rules of the game", a ritualised AMU, different perceptions of risk, a "prescribing etiquette", "the good farmer", "the good veterinarian", "treatment culture" and emotions such as frustration and fear could potentially shape the collaboration and the possibility to change AMU. The modified Theory of Planned Behaviour used in this article has not directly exposed nor explained any of these mechanisms, rather it has thematised the factors of importance. These factors have been explained and elaborated further through theoretical concepts to better understand the context surrounding the farmer-veterinarian collaboration when working with AMU.

As a result, there is a need for more studies with a focus on both individual actions and the structures surrounding them. The individual actions are those relevant to the daily life of a veterinarian and a farmer working together and making individual and collaborative decisions on AMU. However, the structures surrounding them are just as important as they permeate and affect their local realities. We have limited knowledge on the effect of changes in social and biological processes on farmers' and veterinarians' motivation and AMU levels over time. Therefore, studies conducted in the intersection of qualitative and quantitative research to investigate the actual level of AMU and the motivation to change this over time within the HHM setting are needed.

Furthermore, there is a need to combine the methodological approaches of veterinary and social science literature. A more holistic approach, intertwining the theoretical perspectives of the two research areas will work synergistically to address the required change in AMU in dairy cattle. The research should acknowledge the fact that everyday decisions and actions related to AMU lie in the collaboration between farmers and veterinarians. However, this must be combined with reflections on the effect of the outside world, which surrounds and defines the farmers' and veterinarians' local mode of action.

Conclusion

We have summarised the available international literature on factors that influence farmers' and veterinarians' intention to use antimicrobials rationally. This has made it easier to interpret this knowledge in relation to VHHC, which comprises one of the primary settings for working with rational AMU in the production animal sector. Awareness of the identified factors within VHHC can improve the effort to reduce AMU. New perspectives have nuanced the understanding of why and how many of the identified factors are at play within this collaborative context. Important topics have been identified, such as social norms including pressure from social networks, diverging risk perceptions and the importance of trust in the working collaboration. This highlights the importance of communication in improving the understanding of other people's perspectives as well as common goal setting within VHHC. We have identified that not all factors are of equal interest across countries, e.g. legislation and types of advisory services. Moreover, the economic models for veterinary practices differ from country to country, affecting the specific meaning and importance of a given factor.

The included literature and research, which was conducted primarily within the field of veterinary research, focuses on the individual farmer and/or veterinarian and their perspectives on AMU and potential for change within the VHHC setting. However, the review study has identified a request from both farmers and veterinarians for national or international solutions to the AMR problem, for example support from the industry and a new discourse among consumers and media. These solutions go beyond an individual's frame of action. Within the field of social sciences, there has been a focus on the structural dimensions related to AMU, supporting the need for and investigating these national and international perspectives. We argue that future research would benefit from a combined focus on the individual and collaborative actions of farmers and veterinarians within the VHHC setting that frames the everyday choices of AMU in intensive dairy farming. However, the overall structural framework (historical, biological, economical, etc.) surrounding and defining the actions of farmers and veterinarians must also be considered. We have therefore identified a need for studies that bridge the theoretical perspectives of veterinary research and social sciences in order to understand the potential to change AMU within VHHC in dairy cattle farming.

Conflicts of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Author contributions

NS, DB and LN contributed to the design and conception of the review study. The literature search was conducted by NS. Analysis and discussions of the included literature were performed by NS, DB, CJ and LN. NS produced the first draft of the manuscript, which was redrafted and edited by DB, CJ and LN. All authors contributed to the article and approved the submitted version.

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9.2 Manuscript II

The antimicrobial landscape as outlined by Danish dairy farmers

Nanna Krogh Skjølstrup,[1*] Dorte B. Lastein,[1] Carsten S. Jensen,[2] Mette Vaarst,[3]

[1]Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, 1870 Frederiksberg C, Denmark
[2]Department of Sociology, Faculty of Social Sciences, University of Copenhagen, 1353 Copenhagen, Denmark
[3]Department of Animal Science, Aarhus University, 8830 Tjele, Denmark

*Corresponding author: Nanna K. Skjølstrup, Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, Grønnegårdsvej 2, DK-1870 Frederiksberg C, Denmark. Email: nannaks@sund.ku.dk.

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Abstract

Limiting antimicrobial use (AMU) in dairy farming is an important step toward reducing antimicrobial resistance (AMR). Therefore, it is relevant to understand dairy farmers' choices and the potential for change in relation to AMU, even in countries with low usage. Furthermore, there is an increasing recognition of the need to focus on both the individual farmer's behavior as well as the context surrounding and influencing the farmer's decisions in relation to AMU if the goal is for further reduction. To date, no studies have taken into account both the individual farmer and their context in both conventional and organic dairy farms under Danish conditions. For this study, 15 Danish dairy farmers were interviewed using qualitative semi-structured research interviews, and the notion of landscape was used to describe the context of their AMU. We found that AMR was considered to be a distant element of the farmers' antimicrobial landscape. Daily challenges such as acutely diseased animals and poor housing conditions seemed more urgent and overruled the threat of AMR. We also found that interviewed farmers had differing opinions on farm management, partly shaped by changes in legislation and ways of farming over time. At one end of the scale, some organic farmers had rethought the current way of farming; keeping robust animals in a natural setting was expected to prevent disease. They were positive about legislation, and the numerous restrictions on AMU over time were thought to contribute to ensured quality for consumers. At the other end of the scale, some conventional farmers perceived disease as something that should be controlled trough treatment, and the currently eased legislation and intensification of farming had legitimatized AMU for this purpose, leading to an expectation among these farmers of certain rights to handle medicines themselves. These contrasting views might lead to inspiration and competition in terms of reducing AMU, as the farmers appeared to value the opinions of other farmers, and they were found to continuously assess each other. Through such ongoing assessment, pioneers of AMU reduction – whether organic or conventional – might motivate their colleagues to change their AMU. Future research should address the potential of experience- and attitude-sharing among farmers as motivation to reduce AMU.

Key words: antimicrobial resistance, farmer perceptions and choices, societal context.

Introduction

The use of antimicrobials for both humans and animals has caused a rising global challenge of antimicrobial resistance (AMR) (Laxminarayan et al., 2013; Tang et al., 2017). Reducing antimicrobial use (AMU) in dairy farming is therefore one area of importance (WHO (World Health Organization), 2015). Despite a generally low level of sales of antimicrobials in Denmark (EMA (European Medicines Agency), 2020), antimicrobial consumption in cattle has been at the same level for the past five years, with a slight increase in consumption among calves over the past year (Korsgaard et al., 2020). Therefore, a further reduction in AMU in Denmark is of continued importance. Dairy farmers are some of the central actors when working toward reducing AMU in agriculture. In many countries, dairy farmers administer antimicrobials without having to consult a veterinarian, and it is therefore important to understand the perspectives of the dairy farmer, his or her individual opportunities for and interests in reducing AMU, and the influence of their surroundings (Golding et al., 2019). Qualitative research methods such as semi-structured interviews are appropriate for this purpose as they allow participants to speak freely about a topic and can thereby uncover important aspects. To date, no such research on dairy farmers' decisions and thoughts on AMU has been conducted under Danish conditions and involving both conventional and organic dairy farmers.

There is an increasing awareness of the importance of "context" in trying to understand farmers and their potential to change their AMU, as opposed to a sole focus on individual behavior (Chandler, 2019; Adam et al., 2020; Begemann et al., 2020; Rynkiewich, 2020). The notion of landscape can provide a framework for describing the structures and actors involved in a given context (Ormond, 2016; Tsing, 2017). Based on previous research within the area, the current landscape of AMU in Danish dairy farming is expected to involve different actors such as consumers, the media and veterinarians (McIntosh and Dean, 2015; Swinkels et al., 2015; Golding et al., 2019; Wemette et al., 2020), as well as physical settings such as the farm and barn environment (Buller et al., 2015). Furthermore, cultural and political circumstances such as legislation (Fischer et al., 2019) and current discourse on AMR in the media and society (Buller et al., 2015; Golding et al., 2019; Wemette et al., 2020) are expected to influence the antimicrobial landscape. We expect these landscape structures to affect the individual dairy farmer's views and understanding of their situation with regard to AMU.

According to Tsing (2017), a landscape is temporal. It is therefore important to consider the history and developments of the constantly changing context in order to understand current and future perspectives and actions related to AMU and AMR. An example of a changing context and an important aspect of the antimicrobial landscape could be international farming conditions moving toward centralized, intensified and increasingly efficient farming (OECD/FAO (Food and Agriculture organization of the United Nations), 2018; Clay et al., 2020). Similarly, in 2019, Danish dairy production consisted of 566,640 dairy cows distributed across approximately 2,800 farms, delivering 5,614 million kg of milk to dairies, of which approximately 12% was organic. Back in 1993, a slightly higher number of dairy cows were distributed across six times as many farms, delivering less milk in total, of which less than 1% was organic (Statistics Denmark, 2019). Both

Danish and international farming conditions have therefore changed, just like the context in which choices about AMU are made.

As evident from the numbers above, organic farming in Denmark has developed in magnitude over the period. The conditions for organic farming have also changed. The first law on organic agriculture was presented in 1987, followed by multiple action plans and notable economic incentives over the following decade (Halberg et al., 2008). Under Danish conditions, the premium for organic milk is approximately 20% higher than for conventional milk (Bro, 2021). Internationally, certified organic milk makes up only 0.9% of the global market, yet the share has been growing over time (KPMG, 2018).

Consumer demand for organic food has increased in Denmark (Statistics Denmark, 2020) due to health, environmental and animal welfare perspectives (Grunert et al., 2000; Halberg et al., 2008). Furthermore, it has become important to avoid pesticides and medicine residues, which helps to create a positive view of organic production under Danish conditions. Megatrends among Danish consumers go hand-in-hand with this perception of organic food (Halberg et al., 2008). These changes in consumer trends are part of the context Danish farmers must navigate in relation to their AMU. Globally, similar consumer trends have been found to influence farming practices (Haggerty et al., 2009).

Legislation is another important aspect of the Danish antimicrobial context. Since national surveillance was introduced in 1995, all AMU by farmers has gradually and to a large extent been determined by legislation. Elements of AMU control include national surveillance of AMU, antimicrobials exclusively prescribed by veterinarians, thresholds for maximum usage without government supervision, and limitations on the use of specified antimicrobial substances. However, since 2006, conventional Danish dairy farmers have generally been allowed to have medicines available at the farm for treatment of certain defined diagnoses, along with a requirement for regular "obligatory" veterinary visits, the frequency of which depend on the type of veterinary agreement[1] (Ministry of Environment and Food of Denmark, 2018).

Organic farmers, by contrast, need a veterinarian to initiate all treatments (Organic Denmark et al., 2020). Furthermore, withdrawal times for meat and milk are twice as long as for conventional products, and organic farmers are not permitted to use all of the medicines available on the market (The Danish Agricultural Agency and Ministry of Food Agriculture and Fisheries of

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[1] Farmers can choose between four different types of veterinary agreements. Two of these, "Module 1" and "Module 2", are mostly directed at conventional farmers as they have more freedom to use medicines on the farm. With a "Module 1" agreement, typically chosen by conventional farmers with a smaller number of animals, the veterinarian must initiate treatment for adult cows, but the farmer may finish the treatment course using medicines prescribed by the veterinarian. With a "Module 2" agreement, typically chosen by larger conventional farms, the farmer can initiate treatment of defined diseases in all animal groups, but the veterinarian must visit more regularly. The last two types of veterinary agreements, known as basis agreements, are often relevant to organic farmers. No extra allowances with regard to medicine use are granted here, however, the veterinarian only needs to visit once or twice per year according to the type of agreement (Ministry of Environment and Food of Denmark, 2018).

Denmark, 2018). Danish legislation has changed frequently over time, thereby changing the terms of AMU for all Danish farmers.

Investigating perspectives of farmers with a low average AMU at a national level, here personified as Danish farmers, while reflecting on their context (i.e., the landscape of AMU) might provide new insights into how changes in context can influence farmers' choices, and how to promote future AMU reduction in a global context. The aim of this paper was to explore the antimicrobial landscape from the perspective of Danish dairy farmers. This topic was approached inductively, using semi-structured interviews with Danish farmers to explore their perceptions of AMU and their current practices, as well as opportunities and obstacles in terms of changing this practice. The notion of landscape provided a useful metaphoric tool for structuring, understanding and discussing the results of the analysis. As a part of this discussion, notable variations in the farmers' landscapes were investigated to further understand the implications of these differences.

Materials and methods

The project complied with relevant Danish and International standards and guidelines for research ethics, and approval was granted by the Research Ethics Committee for Science and Health, University of Copenhagen (ReF: 504-0066/19-5000). Furthermore, the project complied with the rules of the General Data Protection Regulation, and approval was granted (Ref. no.: 514-0312/19-3000). The study has been reported in line with the COREQ checklist (Booth et al., 2014).

Participants and recruitment

A participation matrix of farming type, age, employment status and gender was created to ensure variation among recruited participants. Inclusion criteria included people working with cattle for commercial purposes and those in charge of the everyday treatment of the animals and treatment decisions. The matrix was filled out using the researchers' professional network of dairy farmers (i.e., through purposeful sampling) and interviewed veterinarians' (part of a related study) network of farmers (i.e., through snowball and purposeful sampling). Only dairy farmers without an established relationship with the interviewer (first author) were recruited. Recruitment continued until data saturation was achieved, meaning the time when elements brought up by the interviewees tended to be redundant of what was collected in previous interviews (Fusch and Ness, 2015).

Interviewees were contacted via telephone by the interviewer, who introduced herself as a researcher from University of Copenhagen interested in the farmer's opinions on AMU in dairy farming, and briefly explained the practicalities before asking if the farmer wanted to participate. Three of the 18 farmers declined due to time constraints. Before an interview was initiated, every participant signed an informed consent form, thereby agreeing to participate and allowing the transcribed interview to be used for analysis. The informed consent form consisted of a brief summary of the project, ensured the participant complete confidentiality, and informed them of their right to withdraw from the interview at any time before data analysis was initiated. No participants withdrew their consent.

Interviews

Between September and November 2019, the first author conducted all of the interviews using a qualitative, semi-structured approach. Prior to the interviews, the first author made a declaration of preunderstandings to be able to uniformly and openly meet the interviewees. This declaration included the first author's own background (formerly practicing veterinarian, PhD student at the time of the study), previous experience with farmers, veterinarians and the use of antimicrobials, perception of prudent AMU and expectation of replies from interviewees. The first author had no previous experience of conducting interviews, but attended several practical courses in interview techniques, and conducted three pilot interviews of non-included farmers to practice and adjust the interview guide before initiating the interviews for this study.

All interviews were conducted in Danish, at the interviewee's workplace, either in a quiet office at the farm or in the farmer's home, without disturbance from other people. A cozy and trustful atmosphere was sought to encourage interviewees to speak openly. Interviews followed an interview guide covering seven themes (Table 1) with a gradual increase in the level of abstraction, lasted approximately 90 minutes (range: 75 to 120 minutes), and were audio recorded. At the beginning of the interview, interviewees were ensured confidentiality and encouraged to direct the course of the interview themselves. The interviewer was responsible for keeping to the themes of the interview guide. During the interview, any uncertainties or contradictory statements were elaborated; the interviewer repeated central statements and the interviewee confirmed or corrected this interpretation. At the end of the interview, the interviewer performed member checking, i.e., gave a brief summary (on average 16 minutes) of main noted key points of the interview in order to give interviewees the opportunity to correct or add any information.

Table 1 Themes of the interview guide used in the interviews

Interview guide
- The last treatment at your herd (motivation, course, decisions, communication) - Collaboration with veterinarian (format, motivation, changes) - Medicine use in your herd (responsibility, goals, experience of antimicrobial resistance) - Knowledge of antimicrobials and resistance ("correct antimicrobial usage", information sources, antimicrobial resistance) - Attitudes about antimicrobial usage (own, society's, colleagues', veterinarians', employees', advisors') - Change in antimicrobial usage (motivation, future use, ways or methods to achieve this) - Surroundings (systems, legislation)

Interview analysis

After every interview, the interviewer gave a reflective commentary with immediate thoughts and impressions from the interview, and relevant adjustments were made to the interview guide as part of the iterative process. The first author transcribed all interviews in order to ensure continuity and in-depth knowledge of the data. Since the primary focus was on the meaning of the interviews, they were transcribed using a non-verbatim approach. Member checking at the end of the interview as well as continued repetition of statements during the interviews to ensure correct interpretation by the interviewer meant that the transcripts was not returned to the participants for further validation.

Transcription and coding were done using NVivo version 12 Plus software (QSR, International: https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home/). For the transcriptions, an asterisk (*) was used if names could be easily recognized, square brackets were used to provide explanatory information, and […] was used to indicate where a quote had been shortened. All interviews were analyzed by the first author inspired by the inductive methodological approach used in grounded theory (Corbin and Strauss, 2015). First, meaning condensates (sequences of statements given a heading in line with the content) were created through open coding, thereafter axial coding was performed to identify themes across interviews. The approach was not strict grounded theory, even though the codes and themes were identified through an inductive coding process. This was because new theories were not created; instead, the identified themes inspired the use of the landscape framework, as presented in the introduction. The landscape framework has previously been used within other scientific fields, i.e. anthropology (Tsing, 2017); in this paper, we found the term useful to collectively describe the identified themes. Coding procedures, the contents of themes and the meaning of central citations were discussed in the author group, and citations used in this paper were translated to English by the first author. An overview of the coding tree can be seen in Table 3, in the Appendix.

Results

A total of 15 farmers from different geographical locations across Denmark were interviewed. Participants included 6 organic farmers (2 women, 4 men) and 9 conventional farmers (5 women, 4 men). In addition to a relatively even distribution in gender, farmers of different ages and employment status were represented in both faming types. The individual characteristics can be found in Table 2. The audio recording failed for one interview (FC10), but the reflective commentary and impressions from the interview still contributed to the results of this study.

Table 2 Individual characteristics of interviewees

Identity O (organic) C (conventional)	Type of farming	Gender	Age	Employment status	Farm size (no. of cows)
FO1	Organic	Female	< 40 yr	Employee	120
FC2	Conventional	Female	< 40 yr	Owner	95
FO3	Organic	Male	< 40 yr	Employee	150
FO4	Organic	Male	< 40 yr	Owner	210
FO5	Organic	Female	> 40 yr	Owner	220
FO6	Organic	Male	> 40 yr	Employee	160
FO7	Organic	Male	> 40 yr	Owner	580
FC8	Conventional	Female	< 40 yr	Employee	310

FC9	Conventional	Female	< 40 yr	Employee	220
FC10	Conventional	Male	< 40 yr	Employee	390
FC11	Conventional	Male	< 40 yr	Owner	430
FC12	Conventional	Female	> 40 yr	Employee	390
FC13	Conventional	Female	> 40 yr	Owner	190
FC14	Conventional	Male	> 40 yr	Employee	250
FC15	Conventional	Male	> 40 yr	Owner	330

Danish farmers' antimicrobial landscape

Analysis of the transcribed interviews resulted in 6 themes or central landscape structures that formed part of the interviewed Danish farmers' antimicrobial landscape. The landscape structures had different local and global relevance to the interviewees. "The available toolbox for treatments", "the local farm setting" and "the veterinarian – an integrated partner or rare visitor on the farm" were all structures that closely affected the farmers' local and everyday farming environment in concrete and practical ways. Both "legislative structures" and "other influential actors" were on the border of local and distant relevance to farmers, whereas "antimicrobial resistance as a distant element" was an abstract term present in a more global context. Every interviewed farmer had their own individual view on the landscape, while the spectrum of individual perspectives collectively described the common antimicrobial landscape of the interviewed Danish farmers.

All landscape structures will be explored in the following sections. They will be elaborated and nuanced with a starting point in the individual interviews (identified as FO1 to FC15 for organic and conventional farmers, respectively). Selected citations from these interviews will be used to exemplify important aspects.

Local structures of the antimicrobial landscape

Theme 1: The available toolbox for treatments

Starting with the farmer's local context, an important structure of the antimicrobial landscape involved perspectives about concrete and practical treatment situations – when an animal should be treated, how it should be treated, and for how long. Decisions about these questions were influenced by the interviewees' thoughts on the "correct use of antimicrobials" and the type of available medicines (including treatment methods, which were alternative to antimicrobials). We chose to use the metaphor 'toolbox', covering both the spectrum of available substances and methods to treat with, as well as perceptions and the given legislative framework, because every treatment substance or method was guided and decided by this and could therefore not be seen separate from it. Therefore, we call it 'the available toolbox'.

"Penicillin" was used as a common name for antimicrobials in most interviews. The farmers did not distinguish between types of antimicrobials, and penicillin was used as a synonym for all classes of antimicrobial substances. Furthermore, a misunderstanding of broad-spectrum antimicrobials was evident from the interviews, i.e., that Penovet (benzylpenicillin procaine) was an example of a broad-spectrum antimicrobial due to its application for many different types of diseases, which is why it was perceived by the interviewed farmers to be inappropriate to use as first-choice.

As mentioned in the Introduction, an extended set of rules governing medicine use apply to organic dairy farmers. These additional legislative rules added an economic layer to decisions about treatment for the organic farmers. Some organic farmers indicated that they preferred antimicrobials administered in a way that could ensure as short a withdrawal time as possible due to the double withdrawal time applying for treatments in organic farming. This preference was also mentioned by a few conventional farmers. For example, the withdrawal time could be more than halved if some types of antimicrobials were given intravenously instead of intramuscularly. This has led some organic farmers to request certain methods of administration from their veterinarian. Furthermore, the value of a diseased animal was considered carefully before the veterinarian was contacted. The chances of a sick calf being treated at the weekend was therefore poor, as prices for veterinary assistance are often highest out of hours. FO6 described how leftover medicines originally prescribed for another animal could even be used for the sick calf in order to avoid veterinary expenses (or killing the animal), an action that is not permitted according to Danish legislation: [FO6] "*We had received some medicines* [from the veterinarian] *to complete treatments when we had some other calves treated. Then, at the weekend, I could treat a calf with fever… However, if we had not had any medicines… it's too expensive to call the veterinarian in terms of the value of the calf. Then it's actually better to euthanize the calf. That is bad, actually*."

Some organic farmers wanted to reduce their use of what they perceived as "unnecessary AMU", also referring to financial considerations. Instead they used alternatives to antimicrobials, as explained by FO4 in the case of mastitis: [FO4] "*We don't treat any mastitis cases… Actually, that's not true; we can treat an* [Escherichia] *coli infection, and a first-parity cow, but these make up less than ten cases annually, so as good as none. Anyway, our strategy is not to treat mastitis. Instead, we use peppermint lotion and perhaps painkillers. However, we do not often use painkillers for a regular mastitis case […]*". In addition, the use of antimicrobials for dry cow therapy could be less frequent for some organic farmers who perceived this type of treatment as prophylactic: [L7] "*It is very rare* [that we use dry cow therapy]*. I think… I don't know, perhaps once or twice annually, but not often. I know that my boss dislikes the fact that some farmers regularly take milk samples and more or less treat the cows preventively at dry-off*."

An acute mastitis case would be managed completely differently in FC15's conventional herd, where treatment with antimicrobials was initiated to relieve pain and discomfort regardless of the stage of lactation: [FC15] "*I don't want to have a sick cow walking around that I can't treat. That's just how it is. If they have a fever, they will be treated. Whether or not it's mastitis and whether the cow will be dry in 2 months or 14 days. That's how I feel, and that's what I have told the veterinarian*.* [Mimics the veterinarian] *"Well, you gain nothing from that* [treatment], *the cow will have recovered in 3 days anyway". Well, that may be, but that's how I want it*."

Medicines and treatments appeared to be a more obvious choice for many of the interviewed conventional farmers compared to the organic farmers. The consequences of antimicrobial treatment were not as wide-ranging as for organic farmers, as there were few expenses and the medicines were available. Farmers talked about the "correct use of medicines" differently: it could either mean timely intervention, or delaying treatment for a few days in some cases, e.g., until the disease had developed further or a diagnostic answer was available. This was described by FC12: "*Well sometimes I delay treatment for a day. Perhaps I'll try giving the calf water with sugar, and I am very attentive toward it […] What if I can't feel anything at the umbilicus that day? We want to use as little penicillin as possible, so sometimes we might delay for 1 day so that we are better able to correctly diagnose the calf. Then I won't need to treat with one type* [of antimicrobial*] and then change it.*" This makes it easier to choose the correct antimicrobials according to the diagnosis. The correct duration of treatment course was also highlighted as important by some farmers.

Some organic farmers placed great value on naturalness and robustness. The idea was to ensure robust animals so that disease and treatments could be avoided, as elaborated by FO3: "*If an animal is sick, it should leave this herd. It is a weak animal and not one we should breed from […] Nowadays, farmers only breed animals that are expensive to keep and need a lot of attention in relation to medicines, feed, and all kinds of things […] When I am in charge* [at this farm]*, the animals will be my tool to maintain our ecosystem. The cows' purpose is to harvest the grass and make sure it's kept at the right growth stage. Then you need cows that will stay healthy when they are only fed grass and not all weird kinds of feed […] Cows are meant to eat grass, so they should not be fed anything else*." In addition, other organic farmers expected that letting the cow and calf be together as nature had intended would ensure a sufficient transfer of immunoglobulins from cow to calf.

Some organic farmers also talked about the "correct use of medicines" with some of the same phrases illustrated above. For example, the belief that the treatment course must be finished, and using the argument "sick animals need treatment". This was exemplified by FO6: "*There are many farmers trying to avoid even the smallest amount of medicine. I don't agree with that. I believe that if you are sick, you should be treated in order to recover. I think that discomfort goes against the idea of animal welfare. That's my point of view. However, there are some farmers who have the opposite opinion, who think we should avoid treatment as far as possible*." However, finishing the course of treatment could conflict with some of the previously mentioned limitations for organic farmers, such as extended withdrawal times and veterinary costs.

Both organic and conventional farmers used alternatives to antimicrobials, but for the organic farmers, alternatives represented an opportunity to treat where veterinary assistance could be avoided. Furthermore, organic farmers mentioned a larger variety of alternative products, e.g., active coal, electrolytes, acidifiers for calves' milk, homeopathy, and peppermint lotion, teat amputation or drying off single teats in cases of mastitis. Conventional farmers used other alternatives, e.g., water with sugar for calves and peppermint lotion for subclinical mastitis cases. Both were used as tools to postpone (or perhaps avoid) treatment.

It became evident through the interviews that individual farmers perceived the “correct use of antimicrobials” differently, e.g., diverging perceptions of the optimal duration of treatment. Furthermore, a wide range of approaches to e.g., the treatment of mastitis – both acute and subclinical – were presented. Different farmers perceived each of the approaches to be the “correct” approach. However, all farmers believed the available toolbox for treatments was entangled with legislation, personal attitudes to pain and discomfort and the control thereof, social norms in relation to their own perception of colleagues’ treatment choices, and the veterinarian’s attitude toward treatment. These were all important aspects and structures of their antimicrobial landscape.

Theme 2: The local farm setting

The local farm setting was another important structure of concrete and practical relevance in the interviewed Danish farmers’ antimicrobial landscape. This included the physical framework as well as the economic status of the farm.

Some framework-dependent challenges were revealed, such as housing conditions, which could make it difficult for both conventional and organic farmers to live up to their own perception of the “correct use of antimicrobials”. For example, poor ventilation was assumed to result in cases of pneumonia and mastitis in the warm summer months. The issues with poor ventilation was exemplified by FC14: “*We have groups* [of calves] *that are not that big, and then three get pneumonia. You think: well I can treat the three with pneumonia today and then wait two days to treat the three other calves. Or I could treat all six at once. It’s probably not correct, but it’s the solution being used. I have seen so many times what happens if I don’t do it that way… I know that it’s scientifically incorrect.*” It was difficult to regulate temperature and ventilation in old cowsheds and this posed a challenge to young calves in particular. In addition, not being able to clean the boxes properly before introducing a new group of calves due to overcrowding was also mentioned as a considerable challenge. FC2 illustrated how this was handled: “*[…] For example, when the calves go from individual housing to group housing, I treat them for coccidiosis. I think it’s mostly a safety precaution because he* [the veterinarian] *thought we should try to avoid it. So we did – we tried it, but I thought our calves became ill at once. Now, we don’t need to discuss it anymore. Our level of medicine use is generally very low, so we just accept that this is the way it is. We have tried not to* [treat]*, and the calves did not look as good as they do now*.” The farmer may have accepted loosening the safety net (the preventive treatment) for a period, but experienced an increase in disease frequency and felt a loss of control. The fact that the farmer had attempted to change the conditions and at the same time perceived the general treatment level of the farm as low appeared to justify the present state of affairs.

Some organic farmers wanted to provide the animals with less restrictive “physical frameworks” and related this to considerations of robustness. In their view, the animals should be able to manage in the physical setting and e.g., eat their original natural feed, such as grass, which was thought to strengthen the cow’s immune system. Furthermore, being out on pasture allowed the cows to move away from their own manure, which was not possible inside a cowshed. FO1 described this notion: “*[…] You need to think about the production – what kind of animals you have, how they are built according to digestion and processing of food, and therefore which feed they* *should have. This approach will help you go a long way. It might be that you need to accept that the yield will reduce slightly and that you can't push your animals as hard. […] The problem is that you* [in the farming society] *have a strategy where everything is pushed to the limit, where you push the cows that much that it takes very little before some of them break down. I don't believe in this strategy.*"

Some organic farmers questioned the way animals are kept in the majority of herds today, i.e., with animals housed inside all year round, fed a variety of high-density feed. Instead of thinking about solutions within the current framework, they used the animals' natural behavior as inspiration to dream about a future with robust animals in a natural setting without production or framework-dependent diseases. However, this seemed to be a compromise with the current milk yield.

Some organic farmers were also thinking about solutions within the current framework, such as seasonal calving, where the most valuable calves were born first and thereby got housed in clean pen conditions with a low infection pressure, as explained by FO4: "*[…] It's easy with the calves. We only have Jersey calves in August and the beginning of September. When we have our Jersey calves, the calf housing area is empty; it has been burned, disinfected, and washed. Furthermore, it has been empty since May 1 […]. It runs smoothly for six to ten weeks before cryptosporidiosis enters*." Furthermore, they controlled access to pasture in order to avoid having cows outside on warm summer days. They achieved this by allowing access to pasture at nighttime during the warm periods.

Some farmers reflected on how the framework of the current production negatively affects the animals. The occurrence of cryptosporidiosis was expected in light of the housing conditions, and the increased feeding levels and concurrent higher milk yield resulted in a higher frequency of diseases, as elaborated by FO4: "*Back in the days when we had a lower feeding level and lower milk yield,* [E. coli mastitis] *it was not a problem […]. Now we push the cows a little more and as a result… they probably yield a bit more than 10,000 kg ECM, and then it starts to get a bit trickier.*"

A high milk yield therefore seemed to be incompatible with keeping robust animals. Some interviewed farmers perceived it as though healthy animals would yield more, but only to a certain degree. Above this limit, the animals were pushed too hard, were stressed, and yielded less, as described by FO4, while FO8 also described this balance: "*What I found most awful this summer was the fact that you could see all the high-yielding cows going down; they couldn't manage. Despite this, we all fight to achieve a high-yielding herd. However, I also believe in balance, where you can say: the cows have a high yield, but they also have good health. That's what I want – I want a healthy high-yielding cow, if that's possible.*"

The physical framework could also challenge farmers' chances to live up to their own standards of AMU on a daily basis. The economic status of some herds forced farmers to use existing cowsheds, which posed a challenge to herd health during certain periods. The local farm setting was therefore a rather fixed structure in the antimicrobial landscape for longer periods of time; shaped by economic and structural development, weather conditions, and by the farmers working there. The way these challenges were handled varied between organic and conventional farms.

Some organic farmers had taken the consequence of the negative effect of the physical framework on their animals. They had started to think about alternative production conditions, either within the current framework or by taking a starting point in the natural behavior of cows.

Theme 3: The veterinarian – an integrated partner or rare visitor on the farm
Another structure, which seemed important to the local context of the interviewees' antimicrobial landscape, was their veterinarian's role at the herd. There were large differences in the use of the veterinarian within both organic and conventional herds.

The incentive to extend the use of veterinary services through veterinary agreements is different for organic farmers. Due to legislation, they are not able to have medicines available on the farm. Nevertheless, the veterinarian could play a central role in optimizing an organic herd. For organic farmers, having a veterinary agreement and herd health consultancy was an active choice often accompanied by the desire for an antimicrobial-free production. The veterinarian entered as an active co-player the minute that antimicrobial-free production became the goal: [FO7] "*We are dreaming about getting to a point where we don't need antimicrobials at all, or at least to greatly reduce the need. We are at a low level of use already, which makes me think that when we try to do so, the whole world will look at us like… if we don't treat our animals, they must be mistreated, they must suffer, many things must be wrong. Therefore, I made an agreement with my veterinarian that they should come every Monday and Thursday to start with, but there wasn't much for them to look at. Now they come every Monday*."

In other organic herds, a focus on naturalness and robustness gave the veterinarian a withdrawn role, where they just administered treatments or acted as "firefighters", accessing the herd once the damage had been done. Veterinarians were not perceived as helping with preventive measures and they were not expected to contribute within that area: [FO1] "*[…] Because my focus is less on treatment and more on prevention… I'm not expecting that from him* [the veterinarian]*. It's probably because you traditionally see the veterinarian as someone who treats animals, not so much within the preventive area. Then again, there is vaccinations, etc*…." The veterinarian's lack of insight and understanding about the farmer's way of farming was perceived as causing an increased separation in their collaboration. Instead, the farmers gained experience-based knowledge from other organic farmers in similar situations.

Some conventional farmers described having gradually withdrawn from veterinary assistance, with the exception of that required by law (e.g., herd health visits every 1-2 weeks and the administration of certain types of medicines) and skilled work they not yet mastered themselves. [FC11] "*I get veterinary assistance for digestion disorders and metabolic diseases* [ketosis, abdominal displacement] – *things that need to be listened to* [with a stethoscope]*, perhaps rumen motility or if the abomasum is correctly positioned… Ketosis I can diagnose myself with a strip – that's easy. Overall, it's just the skilled work with the stethoscope; all the things I am not capable of myself that I need help with. Diagnosing a milk fever – that's not* [difficult]*… If it has mastitis, metritis, or whatever it is… Basically, it needs to be something – perhaps reproduction – that I'm not able to feel myself – if there is something wrong with the ovaries. Those are the kind of things I need help with*."

However, the routine tasks related to a herd health visit and the frequent conversations about the herd were of great importance to some farmers. The veterinarian was seen as a collaborative partner who had a lot to say regarding the development of the herd: [FC15] "*There is something about second opinions and the daily contact with him* [the veterinarian]*. The daily sparring partner. The world is not changed on a weekly basis, but it's often a matter of just discussing whether or not we are on the right track […]. It's all about being able to benefit from his experience. The fact that you get someone with an extensive background knowledge and experience to push things in the right direction*."

The need to change AMU was negotiated between veterinarians and farmers. For example, changing from broad-spectrum antimicrobials at herd diagnosis (diseases that the farmer is allowed to treat on his own) to narrow-spectrum antimicrobials. In some situations, the farmer led the way toward a change in AMU based on new knowledge: [FC11] "*Yes, it was the veterinarian who started with it* [use of Eficur, ceftiofur hydrochloride]*. I knew nothing, back then when we started with herd health consultancy. I guess we started it in 2009. Back then, I didn't know… Eficur, 0-day withdrawal* [for meat and milk] – *that was convenient. When they started writing about the need to reduce AMU in "Kvægnyt"* [farmer magazine], *well… it took probably two years to convince the veterinarian that we should reduce the use* [of Eficur]. *I asked him if we could change it to Penovet instead, and he responded: "You can save a lot of milk due to the withdrawal times!" I argued with him, and he's changed it now*."

In other situations, the veterinarian reduced the number of treatments by ending the use of intrauterine antimicrobials for treatment of retained placenta and metritis, as exemplified by FC9: "*When we started I was skeptical. I know they get antimicrobials in their body as well, however, the fact that you have had your arm inside her* [to remove the placenta] *… I know that I'm not supposed to do it, but… I thought it would be nice to be able to leave some antimicrobials inside them […]. At the time, they started talking about how the antimicrobials actually just ended up in the drain, it made more sense* [to stop]. *Actually, it works fine*." Furthermore, AMU was reduced by using vaccination instead of treatment in some groups during periods with high disease frequency, or by changing the treatment limits for mastitis cases during lactation. This meant that cows with mastitis at the end of lactation were not treated, which in some herds included both acute and subclinical cases.

Veterinarian's role in the interviewed Danish farmers' antimicrobial landscape varied, as did their importance in the daily decisions about treating sick animals. Regardless of the type of production, the veterinarian could either be seen as a vital partner or as a mere necessity for the legally required duties in the herd. The veterinarian's work could also change over time if new conditions arose in terms of the framework for the collaboration, e.g., changes to the type of production or the veterinary agreement.

Border structures of the antimicrobial landscape

Theme 4: Legislative structures

Current legislation was another central structure of the interviewed Danish farmers' antimicrobial landscape due to the long history of regulations, as described in the introduction. Legislation was of local relevance to the farmers as it determined their everyday actions, yet it was also a distant structure as the drawing up of legislation was out of their hands.

Some conventional farmers wondered how lines were drawn according to which types of medicines they were allowed to handle. Furthermore, farmers wondered why they were not able to treat a cow with milk fever more than once. Among some conventional farmers, an increased feeling of ownership and need to take over responsibility in relation to the administration of medicines could be seen. Dealing with antimicrobials and related decisions on a daily basis gave them a sense of independence, decoupling the veterinarian, as explained by FC13: "*Nowadays, when we administer treatments ourselves, it's fair to say that we are more competent at giving injections* [than the veterinarian]." Another farmer saw himself as the most experienced in relation to his own herd, and treated animals outside of the defined diagnosis and therefore the legislative framework. The availability of medicines and the right to treat animals early in the course of the disease seemed to boost this behavior: [FC11] "*[…] I had a cesarean section performed the other day, and now the cow has a slight fever. Should I call the veterinarian to treat it or should I just treat it myself with some Penovet? However, it doesn't fit inside a frame* [defined diagnosis]. *Should I then call it metritis? That's probably the closest fit*."

Some of the interviewed farmers who changed from conventional to organic farming (e.g., in relation to a change of job or reorganization of the herd) thought that the organic legislation belittled the farmer. This was because they had previously been able to diagnose and treat their animals, but as organic farmers were no longer allowed to do so: [FO3] "*Yes, when you become an organic farmer, you automatically become less intelligent! You're not allowed to do anything anymore. For example, if you have a sick calf you can normally treat it, but if you're organic – no, then you're not clever enough to realize that your calf is sick, and you need to call the veterinarian in order to treat it. I would say that organic farming takes your freedom away to some degree. I feel like we are regarded as less competent farmers. There are many extra rules because we are not capable of doing this and that, and then someone needs to come and supervise us*." It seems that the allowance to handle medicines independently gave some farmers a feeling of freedom; having this freedom taken away due to the restricted organic legislation caused frustrations and was perceived as a lack of trust in their competencies from society.

The organic farmers who had never been involved with conventional farming perceived the organic legislation differently. They saw it as a necessity that should outwardly ensure quality and differentiate the organic product for consumers: [FO7] "*I'm actually okay with it* [legislation] *as it is. Sometimes you think it would be easier if you could treat that cow on your own… Or we have a cow with milk fever on a Sunday morning and need to call the veterinarian… It costs more than 2,500 DDK – for 15 minutes of work. It makes me think that I could easily have done it myself. That being said, it's also true that consumers trust organic – they know what* [medicines] *have been used on this property. They know what this animal has been treated with*."

Acceptance of the legislation could also be identified among conventional farmers due to aspects related to food safety. They recognized the need to document and register all medicines used so that milk and meat should be free from antimicrobials, and the dairy and meat industry could stand on target for the AMU. Furthermore, they recognized that legislation regulated behavior in terms of AMU: [FC12] "*Yes, it might be that we need to register our use of penicillin and that they keep an eye on us. However, it's also okay that we're not allowed to treat like crazy… To think: this cow is developing mastitis, and if I treat it right away, it can be milked with the rest of the herd even faster*." Besides these elements, some conventional farmers understood it as a kind of trade-off between the availability of drugs and the demand for documentation. Along with the freedom to treat animals themselves, and thereby the chance to alleviate pain quickly, came the duty to register treatments and the use of medicine.

However, a feeling of frustration accompanied this acceptance. For example, the requirement to register all treatments and use of medicine down to the last milliliter: [FC9] "*Of course they* [Danish Veterinary and Food Administration] *need to supervise us. Luckily, it's been a long time since they were last here. However, they have recently visited some of the herds out here, where I think they were too thorough regarding the medicine* [registrations]*… they're not even allowed to deviate by 2 ml… It's difficult to use that medicine bottle sometimes; you almost need to put it all in syringes to know the actual amount*." In this case, there was frustration about the perceived unfair requirements for detailed documentation. Greater flexibility and trust in the farmer's good intentions during supervision was requested.

The existing legislation influenced the farmer's daily life to a large extent and was an important structure of their antimicrobial landscape, as the legislation determined their room for maneuver in relation to AMU. For organic farmers, the legislation had become a way to differentiate themselves from conventional farming. They described low treatment rates, which gave the consumer a reason to choose their organic product. Differences in the legislative framework depending on the type of production and veterinary agreement could frustrate some farmers who had experienced changes in the rules that applied to them. Farmers with veterinary agreements allowing the most freedom in relation to medicines use (e.g. Module 2 agreements) could see an increase in the use of medicines and a perception of the right to treat as a matter of course. In contrast, farmers experiencing more imposed restrictions could perceive this as being due to insufficient professionalism and as a sign of mistrust from society.

Theme 5: Other influential actors

Another central structure of the interviewed Danish farmers' antimicrobial landscape was the influence from various actors besides the veterinarian. This included colleagues (other farmers), who had a more local relevance in the antimicrobial landscape compared to consumers and the media, who influenced from a distance.

Farmer colleagues

Farmers often expressed a clear attitude toward the way other farmers managed their farms. Conventional farmers accused organic farming of compromising animal welfare due to the limits on treatment: [FC11] "*I have some organic colleagues. They have a completely different attitude toward treating animals because they are organic farmers for economic reasons* [organic farmers are paid higher milk prices]*, and I sometimes wonder why they don't treat a specific animal. However, the alternative appears to be the captive bolt gun. You get that sense when they discuss* *what it costs to treat an animal. In relation to mastitis – I couldn't relate to their treatment argument a few years back, but now I understand: it doesn't make sense to treat every mastitis case. However, when they don't treat metritis or other diseases where the cow has a fever and becomes ill, then I disagree…*" In this statement, FC11 implied that organic farmers had varying motives for choosing organic farming, one of which could be an economic incentive due to the higher price for organic milk.

By contrast, organic farmers articulated a constant assessment of their way of farming by the outside world, including their conventional colleagues: [FO7] "*The best inspectors we have are our conventional colleagues! For better or worse without anything negative being said. […] They are not controlling us in a direct sense, but you can be sure they're keeping an eye on us.*"

A perception was expressed by some organic farmers that conventional farming had a higher use of medicines. Increased access to medicines made it easier for conventional farmers to treat, and treatment was described as something anticipated and a fixed part of the herd routines: [FO1] "*I think other farmers have much more systematized treatments – it's part of their routines. In that way, it's not an extra workload. […] I think it's just an aspect of the business – they set aside resources for treatment*." Farmer FO7 also implies a higher level of medicine use among conventional farmers: "*I don't want to expose anyone, but it's easy when the medicine bottle is right there on the shelf. We always treat when we have a sick animal. […] I don't mind that I'm not allowed to treat independently. Again, it's important to distance ourselves from conventional farming. It's about gaining the consumer's trust, and we can never breach that, or we would not be able to maintain our higher prices.*" This illustrates what motivates some organic farmers to leave the treatment to the veterinarian. It has become a way to differentiate themselves from conventional farming and thereby demand a higher price for their products.

Despite being accused of poor animal welfare, organic farmers were of the opinion that they were pioneers when it came to high animal welfare: [FO4] "*I believe that my animals are well. I'm happy to walk through the cowshed, and I'm happy to go to them in the field. I think they have a decent life. Furthermore, I enjoy being an organic farmer and being a pioneer in relation to animal welfare. I'm in no doubt that that's what organic farmers are.*"

Consumers, citizens and the media

Both organic and conventional farmers were concerned about consumers and their attitudes. Some organic farmers perceived the consumer as an active co-player helping to define the development of organic farming through their consumption habits and attitudes: [FO7] "*We don't want consumers to have any doubts. It's the same with our meat sales*… We have a standard organic production system, but I also have a smaller property with beef cattle on pasture. It's simply because consumers expect animals* to be out on pasture, so then we need to follow that*."

Some conventional farmers perceived consumers negatively – as people who lacked knowledge or were judgmental, which caused frustration. This skeptical attitude toward the consumer could also be found among organic farmers. It was the lack of knowledge, interest and understanding of the reality of farming in particular that gave rise to frustration, especially if the consumer's distorted perceptions and wishes led to new requirements from e.g., the dairy company, and the farm had to adjust their production to meet what they believed to be meaningless demands.

However, farmers also described a common positive experience in terms of visitors when conventional and organic herds open their doors e.g. on “Open Farm Day” or “Organic Day” – events where citizens are invited to the farms. The farmers viewed visitors positively when they were open to understanding the farmer’s reality and a constructive dialogue developed. This was also experienced by FC11: “[About “Open Farm Day”] *There was actually a cow that had just had surgery for abdominal displacement, and people realized it was sick – but it had had surgery and had therefore received help, so that meant no further debate was necessary. It was all there was to notice because the rest of the herd looked fine, so there was nothing to debate*.”

The media’s interpretation of farming seemed to preoccupy conventional farmers to a large extent. It gave rise to frustrations due to a perceived unwillingness to understand the reality of farming: [F9] “[About overuse of medicines in farming] *However, when I hear about it in the media, and they just keep on talking about it – it makes me mad! It annoys me – they should come out here! See what things are actually like… That we do not treat like crazy because we feel like it. The authorities watch us thoroughly as we need to register all use. If anyone thinks we use too much, they will tell us so […]*” Politicians’ and the media’s portrayal of the farming industry being responsible for AMR was also mentioned. This contributed to the spread of misinformation, and the lack of research and understanding of the topic frustrated the interviewed farmers.

One conventional farmer who had reduced their use of antimicrobials had a positive attitude toward the potential role of consumers and the media, who could assist in spreading a positive story to inspire others, which was a motivating factor for the farmer: [FO8] “*I often hear about people who say that we fill our animals with medicine. However, I don’t think we do – not at all. I would very much like to get that story out: “Listen to me, you can have a whole herd, 600 animals in total, and we use this much* [indicates zero with her fingers] *medicine. That’s because the animals are thriving and are in great health”. That would be awesome. If we can, then everyone else can too!*”

The actors mentioned in this section and their influence had varying degrees of local relevance to the farmers and their antimicrobial landscape. The way colleagues manage their farms and their own attitudes toward that affected many farmers’ daily decisions, e.g., in relation to treatment options. Consumer and media attitudes and portrayals of dairy farming had a more distant influence, and farmers did not have the opportunity to change these attitudes directly. An exception was on “Open Farm Days”, when they could enter into a dialogue with the consumer. The dialogue presented an opportunity for the farmer to explain about his or her own reality and thereby influence the consumer’s perception of dairy farming. A perception that, according to farmers, was often characterized by misunderstandings and a lack of knowledge. However, some organic farmers also perceived the consumer as a collaborator who should be listened to and followed.

Distant structures of the antimicrobial landscape

Theme 6: Antimicrobial resistance as a distant element

Perceptions about treatments remained concrete to most farmers, and it was something they considered on a daily basis, unlike about AMR, which was a distant element of their antimicrobial landscape. Not all farmers necessarily understood the term "antimicrobial resistance", and a certain discourse was created when AMR was talked about in popular terms, shaped by the way veterinarians or the media spoke about it. Common to both organic and conventional farmers was the global threat of antimicrobials and AMR not applicable in their local reality. Resistance was thought of as being "from somewhere else", and not from your own herd: [FO6] "*We do have some problems with that thing* [AMR], *which we should avoid because it's dangerous if you can't treat an infection in your body. Therefore, we need to look out for it. It's good to focus attention on it, but in general, I hope people only use what is necessary.*"

The risk of resistance was talked about in abstract terms, but some farmers redirected it to concrete actions in the herd. For example, one farmer was motivated to use fewer antimicrobials in the herd, which resulted in the implementation of concrete solutions to reduce the risk of AMR. This included delaying or avoiding treatment for cows with retained placenta that showed no clinical symptoms, and limiting AMU for subclinical mastitis by using only intramammary (instead of both systemic and intramammary) treatment. However, the farmers did not expect AMU in farming to be of importance in relation to the general development of AMR: [FC12] *"[...] It is concerning if we suddenly can't treat really sick people in need of treatment. However, I think most farmers, on the whole, are careful… [...]"* This statement implies that resistance is an abstract threat, not present in the farmers' local reality. Nevertheless, there seemed to be popular sayings such as "you should only use the necessary amount" and "we should try to avoid treatment", which used the distancing terms "you" and "we", not "I".

Other countries such as the USA and New Zealand were mentioned as countries with more pressing issues related to the risk of developing resistance: [FO4] "*I don't think there are any Danish farms where resistance is a big issue compared to the food we import … I remember my way of handling penicillin and animals in New Zealand was markedly different from what I experience here*." The fact that other countries consume more and have bigger issues with resistance seemed to be a reason to accept the current Danish conditions.

In addition to pointing the finger at other countries, Danish swine production and veal calf production were also highlighted. They were accused of struggling to stay below the legal limit for AMU and for the use of herd medication, which has a tendency toward prophylaxis, which is not permitted according to Danish legislation: [FC15] "*The swine farms have acted against their own interest by using medicines the way they do… By using herd medication and such. Prevent with medicines, penicillin. I don't agree with that, it's risky and resistance can develop. However, we don't do that in cattle farming. Of course, we can do many things in relation to prevention and hygiene. However, … I need to be careful what I say, there might be a few veal calf producers who use herd medication. I won't defend what they do. However, that's not happening here. We use penicillin at dry-off for many cows because our cell count is high. We would like to get below 150,000 – that's our goal. We are aiming for that, we have got down to that number and we should be able to again.*

That's why we have chosen to go all-in on dry-off treatments for a time, to see if we can get down there again." The farmer did not perceive his own actions, i.e., blanket dry cow therapy, to be herd medication. The farmer perceived the treatment as temporary and tried to explain the complexity in the herd's challenges with mastitis and the need for blanket dry cow therapy. The farmer seemed to think these conditions justified an intensified use of antimicrobials over a limited time period, thus distinguishing it from more strategic AMU on a general basis in veal or pig farming.

A focus was also placed on hospitals and doctors in terms of their AMU. They were accused of prescribing unnecessary antimicrobials to humans and to a larger extent than within livestock: [FC14] "*I just think that if you look at medicine use in humans compared to animals, I think you'll be surprised. Humans get a lot of medicine. You only need to be at the doctor's for five minutes before they prescribe something for you*."

In contrast to perceptions about treatments, perceptions about resistance remained abstract in most farmers' antimicrobial landscape. It seems that AMR is something that "other people" should be concerned about, where "others" could include dairy farmers in other countries as well as farmers in other industries such as swine or veal calf production. Furthermore, doctors' use of antimicrobials was perceived as an even bigger challenge in relation to the development of resistance.

Discussion

This study explored the antimicrobial landscape from the perspective of interviewed Danish dairy farmers. Especially legislation appeared to be a prominent structure of the landscape, influencing everyday treatment decisions and defining the collaboration with the veterinarian. Furthermore, depending on the type of production, farmers approached disease differently. These findings highlighted the importance of taking the context into consideration when investigating dairy farmers' AMU practices and perspectives. To our knowledge, no such holistic investigation of Danish dairy farmers' AMU has been conducted before.

One of the central findings of the interviews was the variation among farmers in their perception of what "correct AMU" is and when a sick animal requires treatment. Previous studies found that fewer cows were treated with antimicrobials at organic farms, suggesting a different attitude toward the "correct use of antimicrobials" (Bennedsgaard et al., 2003; Zwald et al., 2004; Habing et al., 2016; Antillón et al., 2020; Krogh et al., 2020). As previously identified by Vaarst et al. (2002), the definition of a sick cow could vary from farmer to farmer depending on the farmer's perspective and the situation of the herd, which was similar to the interviewed farmers in this study. According to the interviewed farmers, the landscape structures influencing their perspective on the "correct use of antimicrobials" included legislation, type of production and different actors such as the veterinarian and other farmers. Other studies have found that the opinion of other farmers and the herd veterinarian affected farmers' treatment choices (McIntosh and Dean, 2015; Swinkels et al., 2015; Doidge et al., 2021). Similarly, interviewed farmers seemed to continually reflect on their own treatment choices, especially in relation to other farmers' choices – either as a way for the farmers to distance themselves from other farmers or as validation for their own choices.

The influence of type of production (i.e., organic or conventional) on treatment decisions has previously been investigated. Vaarst et al. (2003) interviewed farmers who had recently converted to organic farming about their treatment choices in relation to mastitis. Converting to organic principles as such did not result in a change in treatment, but new legislative conditions such as veterinary assistance for all treatments resulted in changed management and treatment thresholds for financial reasons. This finding was confirmed under Swedish conditions (Emanuelson et al., 2018) and by some interviewed farmers in this study – the legislative rules for organic farms resulted in a different available toolbox for treatment. However, in contrast to the findings of Vaarst et al. (2003), some of the organic farmers interviewed in our study seemed to have a different opinion about treatment shaped by more than just economic considerations. This mindset allowed them to consider alternative medicines and to avoid disease by introducing natural production conditions before antimicrobial treatment. This different mindset among organic farmers has also been identified in a French study (Hellec et al., 2021), and might be fostered through experience of low AMU, or through the farmer's approach to organic farming and farming in general, and the farmer's reasons for farming organically. Literature has identified a distinction between farmers who perceive nature and diseases as things that should be controlled and defeated, and those who see nature as an ecosystem that they can learn from and be in symbiosis with (Verhoog et al., 2003; Kaltoft and Risgaard, 2006; Alrøe and Noe, 2008). This might explain some of the variation in the farmers' approaches to treatment; perceiving a cow as part of an ecosystem could imply that diseased animals cause an imbalance for the whole system, and solutions might be sought from a holistic perspective. On the other hand, viewing a diseased cow as something that must be controlled might result in quick and effective intervention in the form of antimicrobial treatment.

The physical framework at the farm and suboptimal management have previously been reported as a barrier to prudent AMU (Buller et al., 2015; Ekakoro et al., 2018; Golding et al., 2019). The interviewed farmers in this study and their different approaches to handling the limitations caused by the local farm setting might also be explained by a difference in mindset among some organic and conventional farmers. Some interviewed farmers had seasonal calving, cows on pasture and cow-calf contact within their farming systems, perhaps as a way of approaching challenges more holistically. In a study by Vaarst et al. (2006), organic farmers' approaches to and perceptions of the limitations of the physical framework seemed to vary according to the farmer's progress toward zero AMU. Increasing success in eliminating antimicrobial treatment led to another way of thinking among farmers – that disease was no longer an expected disturbance that needed to be controlled, but instead farmers allowed themselves to think about preventive measures such as outdoor access and using cows with chronically elevated SCC as nurse cows.

The role of the veterinarian varied widely across the interviewed farmers' herds, which is also supported by previous research (Raymond et al., 2006; Vaarst et al., 2006; Duval et al., 2016, 2017; Bonnaud and Fortané, 2020). Among interviewed farmers, the veterinarian's role spanned from performing legally determined tasks and skilled work to being an active collaborator and co-player, regardless of the type of production. It seems as though improved understanding, communication and goal-setting in the consultancy framework is necessary for veterinarians to become interesting partners for all types of farmers (Derks et al., 2012; Farrell et al., 2021; Skjølstrup et al., 2021).

As outlined in the Introduction, legislation has been a part of Danish farmers' antimicrobial landscape for decades. This might explain the general acceptance of the necessity of legislation among interviewed farmers – an attitude also identified among Swedish dairy farmers subject to similar restrictions (Fischer et al., 2019). In contrast, Swinkels et al. (2015) and Wemette et al. (2020) found that the recently imposed restrictions on AMU in the Netherlands and the US, respectively, have led to negative feelings about legislation and society in general among some farmers. This attitude was also identified among some interviewed farmers in our study, primarily among conventional farmers. These farmers questioned the level of restrictions and where boundaries were drawn, and they appealed for more trust from society by allowing them to handle antimicrobials more liberally. The level of supervision was seen as a breach of trust and a lack of acknowledgment of their professionalism from society. It would appear that the liberalization of medicine use introduced in 2006 created a "do-it-yourself" culture among some Danish conventional farmers, who increasingly expect certain rights, and justify and allow themselves liberties in relation to handling antimicrobials.

In contrast, many interviewed organic farmers appreciated the legislation as a way to ensure quality for consumers. Legislation thereby becomes an aid when marketing organic goods, potentially explaining their positive attitude toward it. A different mindset among some organic farmers adhering to organic principles might also explain this (Poizat et al., 2017). This mindset might be shaped by restrictions on AMU, which have increasingly become part of Danish organic values and principles, as outlined in the Introduction (Jespersen et al., 2015).

Levels of legislation on AMU differ from country to country (Kahn, 2016). Previous research has illustrated how a changing discourse on AMR and AMU in agriculture, influenced by politicians, science, consumers, and the agricultural industry has resulted in tighter or eased legislation over time. Based on these legislative changes, AMU has been problematized and legitimatized, respectively. As a result, differences in AMU and legislation levels among countries have increased (Begemann et al., 2018). The liberalization of medicine use for dairy farmers in Denmark in 2006 might have introduced a period of legitimatization, through which antimicrobials have almost become part of the infrastructure in some conventional farmers' landscape, alongside the intensification of dairy farming (Chandler, 2019; Denyer Willis and Chandler, 2019).

The frustration toward the media and consumers expressed by the interviewed farmers has also been identified previously (Swinkels et al., 2015; Ekakoro et al., 2018; Fischer et al., 2019; Golding et al., 2019; Wemette et al., 2020). However, the important role of consumers, the media and politicians in shaping the future of farming and AMU has become evident from both the interviews and the literature (Haggerty et al., 2009; Begemann et al., 2018; Golding et al., 2019; Wemette et al., 2020). As outlined in the Introduction, megatrends among Danish consumers are well aligned with organic principles, explaining the increased demand for organic products. However, as evident from the interviewed farmers, as well as from previous studies (Ekakoro et al., 2018; Fischer et al., 2019; Wemette et al., 2020), consumers' distorted perception of dairy farming illustrates the need for better communication between agriculture and consumers for both conventional and organic farmers (Ritter et al., 2020). This could be achieved by holding more “Open Farm” events, as mentioned by the interviewed farmers, or through other consumer learning activities (Ventura et al., 2016).

Furthermore, continuous assessment among farmers, as identified in the interviews as well as in previous studies (Wemette et al., 2020), might lead to a positive competition toward prudent AMU. Organic farming might have had a head start on this journey due to its general principles and regulations on AMU, closer collaboration with consumers and targeted marketing, and a distinct differentiation from conventional farming (Stock, 2007), which seem to have created a feeling of coherence and collectiveness among organic farmers. This feeling has previously been shown to be important in reducing AMU (Adam et al., 2020). However, other farmers’ opinions and practices are also of importance to farmers. Therefore, AMU reduction by pioneer farmers also tackling animal welfare issues, whether organic or conventional, might act as a driving force for other farmers.

These findings suggest that future research should focus on dialogue about AMU and AMR among farmers from all production types and AMU levels as a tool for increasing understanding and mutual motivation for changing AMU, as suggested by Hamilton (2018) and Vaarst et al. (2007). Meetings with farmers with different opinions about AMU might inspire a change in practices. Furthermore, future research should investigate whether constructive dialogue between consumers, farmers and representatives from the dairy industry can improve consumers’ knowledge of dairy farming and thereby minimize misunderstandings, potentially giving farmers an increased incentive to work collaboratively with consumer preferences. These preferences should preferably support a reduction in AMU.

Several previous studies have identified a lack of knowledge with regard to AMR (Buller et al., 2015; Poizat et al., 2017; Ekakoro et al., 2018; Higham et al., 2018; Wemette et al., 2020). In this study, some of the interviewed farmers also explained that their knowledge and understanding of AMR and antimicrobials was limited. A lack of knowledge about AMR, or a lacking acknowledgement of AMU in agriculture as a risk factor for human AMR, as identified by Farrell et al. (2021), might also explain why AMR appeared to be a distant element of Danish dairy farmers’ antimicrobial landscape. In order to truly appreciate the need to change something, it is vital to know, understand and acknowledge the consequences of doing nothing (Kramer et al., 2017; Wemette et al., 2020). Golding et al. (2019) and Buller et al. (2015), however, did not identify a lack of knowledge about AMR among interviewed farmers. Instead, Golding and colleagues concluded that there were many barriers to antimicrobial stewardship (e.g., economic challenges), and AMR therefore remained a distant threat that was not acted upon. Similarly, poor housing conditions became a barrier for antimicrobial stewardship among some interviewed farmers of this study.

Limitations

During the interview process, interviewees mentioned fewer and fewer new elements, which suggested that data saturation had been achieved. This was supported by the fact that a large variety of production types and farmers were included in the study. Having only one person analyzing the transcripts could be seen as a limitation of this study, however, this approach ensured consistency and alignment between the non-verbal results of the interviews – as experienced by the first author during the individual interviews – and the analysis. Qualitative research is not intended to be generalizable, but because the findings are understood and explained within a context, the knowledge gained from this is relevant in a global context and for discussions about the future path toward prudent AMU in general. A specific characterization of the Danish context is the low average AMU on a national level with a large extent of legal control of AMU, and the antimicrobial landscape structures might appear differently for farmers in other industries and countries. However, knowledge on how the type of production (organic vs. conventional) and changes in legislation might influence farmers' AMU can be beneficial in other national contexts as well. The Danish case can be seen as a critical case; controlling AMU through legislation has not resulted in a clear-cut reduction. Based on that knowledge, other countries can make informed reflections on whether AMU should be controlled primarily through legal restrictions or if alternatives to this approach needs to be considered as well.

Conclusion

This study showed that AMR appeared to be a distant element of the farmers' landscape due to a lack of acknowledgment and understanding, as well as a tendency to blame others for the threat it poses. Daily practical challenges and urgent matters such as acutely diseased animals kept in poor housing conditions combined with the availability of medicines appeared to overrule the threat of AMR. We also identified pronounced differences in daily management and mindset among interviewed farmers, partly shaped by a changing antimicrobial landscape. Farming intensification and changes to legislation on AMU such as the liberalization of medicines in Denmark in 2006 might have legitimized AMU and led to an independent and at times automatized use of antimicrobials among some interviewed conventional farmers. In contrast, some organic farmers focused on avoiding disease via robust animals and alternative housing conditions. Furthermore, they had a positive attitude toward legislation, potentially shaped by exposure to numerous restrictions on AMU over time, with consumer-related benefits. This difference in mindset and ongoing debate among farmers could act as a breeding ground for change, and future research should address the potential of such experience- and attitude-sharing to increase motivation to change AMU.

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Appendix

Table 3 Coding tree visualizing the inductive process going from interview statements and meaning condensates to codes and themes.

The interviewed Danish farmers' antimicrobial landscape			
Example: meaning condensate and statement	Codes	Themes	
Economy: "It's expensive to call the veterinarian, especially when we can make some of the diagnosis on our own. Then you start of doing that"	Economy	Treatment and decisions	The available toolbox for treatments
	Available products		
	Robustness and naturalness		
	Type of antimicrobial		
	Causing bacteria		
	Timing and length of treatment		
Influences between farmer and veterinarian: "My veterinarian once taught me that I should finish the course of treatment, because otherwise the animals could get resistant"	Avoid using antimicrobials	"Correct" use of antimicrobials	
	The responsibility of the veterinarian		
	Use of "penicillin"		
	Different perceptions (criteria, length, type of antimicrobials)		
	Learning by doing		
	Influences between farmer and veterinarian		
Type of production – robustness: "It's all about creating robust cows that can survive on grass"	Employees	The framework of the farm	The local farm setting
	Barn conditions		
	Type of production - robustness		
Someone who treats: "My focus is not on treatment but on prevention. I don't expect that from my veterinarian"	Someone who treats	The role of the veterinarian	The veterinarian – an integrated partner or rare visitor on the farm
	Active collaborator		
	Only a craftsman / what legislation determines		
Accepted, a necessity: "Yes, we need to register our medicine use, and they keep an eye on us. But I think it is okay. It ensures that we don't treat like crazy"	Accepted, a necessity, a way to differentiate	Legislation	Legislative structures
	For the sake of the animal		
	Something that can be changed		
	Meaningless, lack of trust, frustrating		
Conventional farmers use more antimicrobials: "I don't know how	Conventional farmers use more antimicrobials	Others	Other influential

things go about, but I imagine that it is much more focused on treatment”	Lack of painkillers in organic farming - animal welfare issues		actors
Media and society: “If first media gets aware of something, then it escalates”	The consumer (active part of the development or barrier)	The influence from the surroundings	
	The dairy company		
	"Open farms"		
	Media and society		
Other people’s issue: ”I think, if you look at the medicine use for humans, you would be surprised”	Global issue, abstract	Antimicrobial resistance	Antimicrobial resistance as a distant element
	Other people's issue		
	Misunderstood		

9.3 Manuscript III

Danish cattle veterinarians' perspectives on antimicrobial use: contextual and individual influencing factors

Nanna Krogh Skjølstrup,[1*] Mette Vaarst,[2] Carsten S. Jensen,[3] Dorte B. Lastein,[1]

[1]Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, 1870 Frederiksberg C, Denmark
[2]Department of Animal Science, Aarhus University, 8830 Tjele, Denmark
[3]Department of Sociology, Faculty of Social Sciences, University of Copenhagen, 1353 Copenhagen, Denmark

*Corresponding author: Nanna K. Skjølstrup, Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, Grønnegårdsvej 2, DK-1870 Frederiksberg C, Denmark. Email: nannaks@sund.ku.dk.

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Abstract

The global risk for antimicrobial resistance (AMR) can be reduced by reducing antimicrobial use (AMU). Veterinarians are one of the key actors in relation to AMU in livestock, and understanding the dynamics of veterinary treatment and prescription is central to achieving AMU reduction. Veterinary AMU decisions are influenced by a complex pattern of both individual and contextual factors. In this study, we conducted semi-structured interviews with 16 Danish cattle veterinarians to investigate their perspectives on AMU and current practices in a national context with low use and extensive legal control. We found that personal experiences and emotions rather than scientific evidence guided some veterinarians when making AMU choices. Furthermore, less experienced veterinarians felt a pressure to prescribe according to colleagues' and farmers' preferences for certain antimicrobials. We found that changes in Danish legislation seemed to have introduced hesitancy and a lack of motivation within the veterinary profession, and that AMR was perceived as an abstract threat not applicable to the veterinarians' daily professional decision making. We concluded that the lack of field-generated research of local relevance nourished a culture where AMU choices are built on personal experiences rather than scientific evidence, which also diminished the newly educated veterinarians' self-confidence in relation to their AMU choices. Future research should focus on developing locally relevant research on optimal AMU choices and AMR, and the implications of extensive legal control of AMU in livestock farming should be investigated further to find a balance on the path to reducing AMU.

Key words: antimicrobial resistance, veterinarian perceptions and choices, societal context.

Introduction

Reducing antimicrobial use (AMU) is one of the key ways to reduce the occurrence of antimicrobial resistance (AMR), as any use of antimicrobials can increase the risk of AMR (Tang et al., 2017; Schwarz et al., 2018). Veterinarians are one of the primary distributors of antimicrobials, which is why understanding the dynamics of veterinary treatment and prescription and how to change these patterns is a prerequisite for revising and reducing AMU in livestock.

The aim of this paper is to investigate how different factors influence Danish cattle veterinarians' antimicrobial treatment and prescription at a time characterized by an increasing focus on AMR. There is particular focus on a) factors that characterize each individual veterinarian (e.g., personal experiences, feelings, attitudes, perceived risk of AMR, etc.) and b) the context and the contextual factors that influence how the individual veterinarians decide how and when to use antimicrobials. The contextual factors (e.g., legislation, working experience, farmers' and colleagues' preferences, and the structure of veterinary practices) influence and frame how the individual veterinarian will act in specific situations. We argue that there is a close interconnection between the individual factors characterizing a veterinarian and the contextual factors that he or she must act within. These relationships are in focus in this study and the interaction between the factors is explored further in this paper.

Different factors influencing prescribing practices among veterinarians have been identified in the existing literature. Some studies have primarily focused on identifying whether an influencing factor is individual or contextual. For example, with regard to individual factors, personal experience of specific clinical situations and previous treatment responses have been found to influence veterinarians' choice of antimicrobials (De Briyne et al., 2013; McDougall et al., 2017). In addition, personal feelings have been found to influence veterinary AMU, for example the fear of being blamed by farmers if the proposed treatment fails (Gibbons et al., 2013).

Other studies have identified different contextual factors that influence a veterinarian's treatment and prescribing behavior. For example, the structure of veterinary practices and types of veterinary services have been found to influence veterinary AMU (Magalhães-Sant Ana et al., 2017), while another study identified the need for further legal restrictions in the Netherlands to limit the influence from farmers on veterinary treatment and prescribing (Speksnijder et al., 2015a). In addition, Wilm et al. (2021) identified an apparent national context-dependent preference for the route of administration when treating acute mastitis (simultaneous systemic and local treatment) among Danish veterinarians, which varied from the approaches preferred by Swedish and US veterinarians, for example (Persson Waller et al., 2016; Winder et al., 2019). Treatment approaches therefore appear to be influenced by the national context. Furthermore, a lack of fast and effective diagnostic tools was also identified as a contextual factor influencing veterinary AMU (Speksnijder et al., 2015a).

Finally, some studies have stressed the importance of combining both individual and contextual factors to understand how their interaction influences AMU. These studies have shown how individual preferences among veterinarians for using fewer antimicrobials have been 'overruled' by the context in which the veterinarians work. For example, the perception of AMR as a risk and the incentive for veterinarians to adjust their prescribing behavior accordingly could be seen as an individual influencing factor. However, Golding et al. (2019) found that animal welfare considerations often overruled farmers' and veterinarians' concerns about AMR. Furthermore, Helliwell et al. (2019) found that veterinarians and farmers were not sufficiently equipped to recognize resistance at farm level, partly due to a lack of effective diagnostic tools. Therefore, the individual factor of risk perception was influenced by other factors, e.g. contextual factors such as animal welfare status and the availability of diagnostic tools. Whether AMR is perceived as a risk and the influence that this perception may have on veterinary AMU might therefore be better understood when focusing on the complete pattern of interactive factors. In addition, social influence in terms of experienced pressure to prescribe from either colleagues or farmers has been perceived as an individual or interpersonal (Golding et al., 2019) as well as a contextual factor (Speksnijder et al., 2015a; Lorencatto et al., 2018; Borek et al., 2020; Redding et al., 2020). Golding et al. (2019) outlined how veterinarians experienced pressure to prescribe from farmers and described how this could be influenced by individual factors such as feelings about maintaining a good working relationship. In addition, it was influenced by contextual factors such as poor farm management, e.g. the farmer not identifying a diseased animal until a late stage at which treatment was unavoidable, potentially lessening the veterinarians' determination to oppose the farmer's preference for prescribing antimicrobials (Golding et al., 2019). Higgins et al. (2017) also illustrated the complexity in defining social influence as either an individual or contextual factor. They described how the contextual factors of lack of mentorship and time for clinical discussions with colleagues made it difficult for newly educated veterinarians to gain knowledge, which they believed would help them gain trust from farmers and in time increase their influence over farmers' AMU.

These examples highlight the need to move beyond the mere description of influencing factors as either individual or contextual, and instead focus on the dynamics of their interaction, and we will attempt to address this in this paper. This perspective is also in line with observations within social science, where studies are increasingly exploring AMU and AMR, thus acknowledging that AMR is a complex One Health issue involving multiple actors and implying that solving the dilemma of AMR cannot be reduced to a matter of individual behavioral change (Moran, 2017; Chandler, 2019; Broom et al., 2020). As described by Golding et al. (2019), individual behavior is entangled with contextual factors in a reciprocal dynamic, which is why it is important to focus on both individual and contextual factors and the interaction between them to understand their influence on veterinary treatment and prescribing behavior (Chandler, 2019; Fischer et al., 2019; Redding et al., 2020).

Denmark is an example of a country where AMU regulations have been implemented for decades and current AMU is relatively low compared to other European countries. However, we have seen no further reduction in overall AMU in cattle over the past five years (European Medicines Agency, 2020; Korsgaard et al., 2020). Therefore, examining the perspectives of Danish veterinarians in relation to their individual AMU choices, alongside the influences they experience from their surroundings (i.e., through legislation and the structures determining their veterinary work) might contribute valuable insights to future work on reducing AMU in other national settings and further reducing AMU under Danish conditions.

Semi-structured interviews – as used this study – can help to clarify the influence of and interaction between contextual and individual factors as experienced by the interviewed actors in more depth. The topic was approached inductively through semi-structured interviews with Danish veterinarians to explore their perspectives of AMU and current practices.

Materials and methods

The project complied with relevant Danish and International standards and guidelines for research ethics, and approval was granted by the Research Ethics Committee for Science and Health, University of Copenhagen (ReF: 504-0066/19-5000). Furthermore, the project complied with the rules of the General Data Protection Regulation, and approval was granted (Ref. no.: 514-0312/19-3000). The study has been reported in accordance with the COREQ checklist (Booth et al., 2014).

The setting

Danish cattle farmers with more than 100 adult cattle are obliged to choose from four different types of veterinary agreements that each dictate the content and frequency of the veterinarian's advisory visits to the farm (Ministry of Environment and Food of Denmark, 2018). All treatments at organic farms must be initiated by veterinarians (Organic Denmark et al., 2020). Therefore, veterinarians might visit regularly to treat sick animals, yet not within the framework of advisory services, as organic farmers often chose veterinary agreements that involve only one or two obligatory veterinary visits per year. In contrast, conventional farmers are allowed to have medicines available at the farm to treat certain defined diagnoses (prescribed by the veterinarian for certain animal groups) if they choose one of two specific veterinary agreements; the more liberal the access of medicines, the more frequent the visits. Depending on the size of the farm and the animal groups present, 4-26 yearly veterinary visits are required (Ministry of Environment and Food of Denmark, 2018). For example, veterinary visits typically include: evaluation of treated and dead animals since the last visit, evaluation of herd health and production, antimicrobial use, animal welfare (two visits per year with a special focus on this) and biosecurity (special focus once yearly). In addition, veterinarians are required to write farm-specific reports at regular intervals. The Danish Veterinary and Food Administration supervise practicing veterinarians to evaluate their compliance with these regulations.

Participants and recruitment

The inclusion criterion for this study was veterinarians working primarily with dairy cattle. Using a participation matrix of gender, age, and employment status to ensure variation among participants, veterinarians were recruited via the researchers' professional network and official lists of practicing cattle veterinarians (i.e., through purposeful sampling). A small number of the recruited veterinarians were known professionally by the interviewer (first author), but no veterinarians with a close relationship were interviewed. Veterinarians were contacted via telephone by the interviewer, who briefly presented herself and asked if they wanted to share their opinion on AMU in dairy farming in an interview. One of the 17 veterinarians declined due to time constraints. Data saturation was evaluated during the interview process. We concluded that data saturation had been achieved when the 16 interviews were finalized, as no new information came up in the final interviews (Fusch and Ness, 2015).

Prior to conducting the interviews, the interviewer reflected on her background as a former practicing veterinarian and PhD student at the time of the interviews, her own perception of rational AMU and expectations regarding replies from interviewees based on previous experience of the topic. The interviewer had no previous experience of conducting interviews but conducted three pilot interviews to practice and adjust the interview guide, and attended several practical courses in interview techniques prior to the interviews.

At the beginning of the interview, every participant signed an informed consent form, which included a brief summary of the project, an assurance of complete confidentiality, permission for the interviewer to use transcribed interviews for analysis, and information on the right to withdraw from the interview at any time before initiation of the interview analysis. No participants withdrew their consent.

Interviews

Between June and September 2019, the first author conducted all of the interviews using a qualitative, semi-structured approach. None of the interviews were repeated. Interviews were conducted in Danish, either at the interviewee's workplace or home, or in a quiet public place without any disturbance from other people. An interview guide consisting of seven themes (Table 1) directed the interviews, but the chosen order of the themes was flexible and interviewees were encouraged to direct the course of the interviews themselves. Member checking, i.e., a brief summary of the main points of the interview given by the interviewer, was performed during the interview and at the end of the interview to give interviewees the opportunity to correct or add any information (Kvale and Brinkmann, 2014). Interviews lasted on average 80 minutes (range: 50 to 115 minutes) and were audio recorded. No transcripts were returned to interviewees.

Table 1 Themes of the interview guide used in the interviews

Interview guide
- Motivation (what motivates you in your daily work, examples) - Collaboration with farmers (motivation, changes) - Antimicrobial usage (responsibility, information sources, thoughts on treatment: criteria, duration, choice of drug, use of guidelines, diagnostics) - Attitudes about antimicrobial usage (own, society's, colleagues', farmers') - Thoughts on antimicrobial resistance ("correct antimicrobial usage", information sources) - Change in antimicrobial usage (in relation to clients, examples) - Future antimicrobial usage in dairy farming (wishes, perspectives)

Interview analysis

After every interview, relevant minor adjustments were made to the interview guide. Furthermore, the interviewer reflected on impressions from the interview as part of the analysis process. The first author transcribed all interviews to ensure continuity in terms of approach and impressions from the interviews, as well as in-depth knowledge of the data.

Transcription and coding were done in Danish using NVivo version 12 Plus software, and through a non-verbatim approach. An asterisk (*) was used if names could be easily recognized, square brackets were used to provide explanatory information, and [...] was used to indicate where a quote had been shortened. The first author analyzed all interviews, inspired by the inductive methodological approach used within grounded theory (Corbin and Strauss, 2015). First, meaning condensates (sequences of statements given a heading in line with the content) were created through open coding of all transcribed interviews, after which axial coding was performed to identify themes across interviews. Coding procedures and the meaning of central citations were discussed within the author group, and citations used in the paper were translated to English by the first author only. An overview of themes, codes, and selected meaning condensates can be seen in the coding tree in Table 3 in the Appendix.

Results

Sixteen veterinarians were interviewed. They were distributed across gender, age, experience, and employment status (assistant or partner), and came from a geographically representative sample from areas with the largest density of cattle in Denmark. The individual characteristics of the interviewees can be found in Table 2.

Table 2 Individual characteristics of interviewees

Identity	Gender	Employment status	Age	Years qualified	Percentage of time spent working with cattle
V1	Female	Partner	< 40 yr	5	99
V2	Female	Partner	< 40 yr	5	90
V3	Female	Partner	> 40 yr	17	40
V4	Female	Partner	> 40 yr	18	99
V5	Female	Assistant	< 40 yr	4,5	100
V6	Female	Assistant	< 40 yr	1	99
V7	Female	Assistant	> 40 yr	9	100
V8	Female	Assistant	> 40 yr	14	100
V9	Male	Partner	< 40 yr	4,5	98
V10	Male	Partner	< 40 yr	7	100
V11	Male	Partner	> 40 yr	28	98
V12	Male	Partner	> 40 yr	22	90
V13	Male	Assistant	< 40 yr	8	96
V14	Male	Assistant	< 40 yr	0,5	100
V15	Male	Assistant	> 40 yr	19	100

Four distinct themes resulted from the inductive analysis of the interviews. They describe the individual and contextual factors influencing the use of antimicrobials among interviewed Danish cattle veterinarians as follows: (1) personal feelings, experiences, and the availability of medicines and scientific evidence guide everyday treatment decisions, (2) social relations and diverging interests influence antimicrobial use practices, (3) the current legislative and agricultural framework and room for maneuver in relation to antimicrobial use, and (4) resistance is rarely encountered on a daily basis but remains an abstract threat overshadowed by animal welfare concerns. Each of these themes and how they relate to the aim of this paper will be elaborated in the following sections.

Personal feelings, experiences, and the availability of medicines and scientific evidence guide everyday treatment decisions

All of the interviewed veterinarians were influenced by a variety of factors when making treatment decisions. These factors could be individual (such as personal attitudes, experiences or emotions related to previous therapy choices) or contextual (such as the medicines and diagnostic tools available, current treatment traditions, local farm conditions, or available scientific evidence to support a choice of therapy). The extent to which veterinarians appeared to be influenced by these factors varied widely, and the interviewed veterinarians could therefore treat the same type of disease (e.g. mastitis caused by E. coli, retained placenta and metritis) very differently.

Factors influencing and guiding treatment choices included personal and local farm experiences, as mentioned by many of the interviewed veterinarians. This was exemplified by V10: "*If you are aware of a farm history, for example that Penovet* [benzylpenicillin procaine] *hasn't worked for metritis cases, then that will not be your drug of choice! And if you have a good feeling about the response to Norodine* [sulfadiazine trimethoprim] *after evaluating its effect, then you should use that. I also find that is a better choice as it becomes concentrated in the urinary tract.*" In addition, personal experiences at specific farms and with certain conditions guided many of the interviewed veterinarians' antimicrobial choices, as exemplified by V12: "*I typically know if some of my herds are having a bad period, meaning that cows get very sick when they are infected […] It is often to do with the management level on the farm. If they have a high level of management […], I will often be more likely to skip the antimicrobials and settle for painkillers and fluid therapy.*" Certain periods or conditions at specific farms could therefore justify using antimicrobials in cases where veterinarians would normally have chosen not to.

Emotions also influenced treatment choices for many of the interviewed veterinarians, and V1 exemplified this by telling a personal story: "*I had been told by different people* [colleagues and the Danish Veterinary and Food Administration] *to start using only painkillers and fluid therapy. I told the farmer that antimicrobials had no effect in these cases* [*E. coli* mastitis]*. Then the mastitis cases started coming, and we used nothing but painkillers and fluid therapy… And so many cows died… I think five cows in total […] That experience affected me – it was definitely not pleasant […] So now we treat* E. coli *mastitis with broad-spectrum antimicrobials on top of the supportive therapy […] That experience made me feel awful for the farmer.*" For this veterinarian, the unpleasant emotional feeling related to this specific situation had resulted in a change to the treatment regime. Many of the interviewed veterinarians also mentioned how traditions influenced their treatment choices, i.e. the approach to treatment was characterized by habits that were not questioned – ultimately to facilitate everyday treatment decisions.

For many of the interviewed veterinarians, treatment choices were also intertwined with the availability of scientific evidence. For example, V16 believed that there was no clear scientific evidence available, and therefore he continued treating acute mastitis cases caused by gram-negative bacteria with antimicrobials: "*I am not aware of any solid scientific evidence about how to treat mastitis caused by* E. coli*. Therefore, I treat them with broad-spectrum antimicrobials, painkillers, and something in the teat as well* [local treatment with antimicrobials]." In relation to this, some of the interviewed veterinarians highlighted a general lack of valid scientific evidence, which is why personal experiences often guided veterinary AMU. According to V9 and V15, this was because scientific evidence should be based on local, practical experiences as opposed to universal evidence, which they perceived as research conducted under conditions not comparable to the local farm environment. This type of scientific evidence was difficult to create, as described by V15: "*We are often stuck with the fact that creating evidence is time consuming, and I mean scientific evidence created based on practical experiences. The practical experiences are often not tested under the right circumstances as it is too expensive.*"

A few interviewed veterinarians mentioned that taking a scientifically correct approach to treatment was further complicated by pharmaceutical companies perceiving the Danish cattle market as too small and uninteresting in terms of investment, thus leading to certain products going out of production or never being registered under Danish conditions. This includes narrow-spectrum antimicrobials for treatment at dry-off, as explained by V15: "*It is not long ago that I wrote to one of the medicinal companies commenting on this* [the availability of medicines]*. I wrote that I thought it was a matter of time before someone questioned the veterinarians' use of broad-spectrum antimicrobials for dry-off treatments. I criticized them for having no alternatives available […]. Using broad-spectrum antimicrobials for narrow-spectrum issues – that is not okay! We are just lucky that no one has realized this yet, probably because our level of resistance within the cattle industry is low.*"

The acknowledgement that their treatment choices were influenced by personal experiences made many of the interviewed veterinarians request diagnostic tools that could make diagnosis more objective, as explained by V2: "*I sometimes wish for diagnostic tools that are more objective. It is always a subjective assessment when you're standing there having to make a decision, and that depends a lot on your experience as a veterinarian.*" Other suggestions for diagnostic tools that could assist in making the right diagnoses included cow-side blood tests to determine the cause of unspecific fever, identify the causal pathogens, and provide better estimates of prognosis in various cases, e.g., cows in lateral recumbency. The interviewed veterinarians emphasized that these tests should preferably be fast and precise in order to be useful.

Social relations and diverging interests influence antimicrobial use practices

Colleagues' opinions and choice of antimicrobials appeared to be important influencing factors of AMU among interviewed veterinarians, especially for less experienced veterinarians. V9 explained how in his first years as a newly educated veterinarian, he was very attentive and adaptive in relation to colleagues' knowledge and ways of working: "*I was taught to do things a certain way* [in my first job]*, which was my sort of cornerstone, as we do not get that kind of knowledge from veterinary education […]. You never see a case of mastitis in school – that is just how it is, so you are influenced by your first job in veterinary practice – they tell you how to approach a mastitis case.*" Many of the interviewed veterinarians found that their colleagues' choice of antimicrobials could be different from what they themselves would have chosen. This was especially troublesome for the less experienced veterinarians because they often had a different view about the optimal choice of antimicrobials compared to their colleagues. This was explained by V14: "*Some of my colleagues do not want to stop using intrauterine antimicrobials […] If you then choose not to use it in some cases, it will be your fault as a newly hired employee if the cow presents with metritis later on*." In cases where colleagues disagreed over the choice of antimicrobials and there was a lack of cure after treatment, the veterinarian's own working experience became a determining factor in how his or her choice of antimicrobials was perceived and supported by both his or her colleagues and the farmer.

Some interviewed veterinarians, however, described that they were not affected by their colleagues' opinions on AMU choices: [V3] "*I am not always in agreement with my colleagues, and I don't think you need to be […].*" In some of the interviewed veterinarians' practices that had no implemented practice policy regarding AMU choices, differences in use could also foster discussions that may or may not lead to changes in AMU choices. The need for such discussions was highlighted by many of the interviewed veterinarians, however, V9 mentioned veterinarians' need to have an independent attitude about AMU choices: "*We discuss things, but basically every veterinarian decides on their own. I think that is the thing with veterinarians – we are part of an independent profession, we are grownups, well-educated people who have been taught to think for ourselves. No one likes to be controlled from the top down.*"

Agreement about antimicrobial choices among colleagues within a practice, however, was seen as beneficial by most of the interviewed veterinarians as it could minimize the influence and pressure from farmers in terms of AMU choices. This was exemplified by V13: "*By always suggesting the same* [antimicrobials]*, we avoid discussions about AMU choices at the farm. That is good for us, but it also makes it easier for the farmer […] He knows what to expect.*" Furthermore, standardized AMU within a practice was important for gaining respect and understanding from the farmer, but it was also acknowledged that it was difficult to change behaviors and attitudes among very experienced colleagues who had developed their routines based on years of personal experience. As explained by V1, if these very experienced veterinarians were to change their routines, it would indirectly imply that what they had previously done was wrong.

In addition to colleagues, farmers also influenced some of the interviewed veterinarians' AMU practices. This could include situations involving an acute case where the farmer wished to slaughter the cow in the near future, leading to a preference for antimicrobials with a short withdrawal time. Other situations could include the farmer preferring to inject a cow only once, leading the veterinarian to prescribe long-acting broad-spectrum antimicrobials. As with the influence from colleagues, the interviewed newly educated veterinarians in particular had trouble challenging farmer preferences: [V6] "*It can be quite difficult to argue with farmers who have had a* *good experience with some specific antimicrobials, which they then want to be prescribed.*" V14: "*Some farmers are used to having certain antimicrobials prescribed, and you just need to follow that. If you don't, it will be your fault as a newly educated veterinarian if the cow presents with disease later on…*" When facing this pressure to prescribe, the fear of being dismissed from their job was mentioned as the ultimate consequence of not following the farmer's preferences. In relation to that, the structure and culture of veterinary practices can act as a barrier, as veterinarians must consider the threat of farmers going to another veterinary practice if they are dissatisfied with the services provided. This was mentioned by many of the interviewed veterinarians, irrespective of their level of working experience. V1 described how the structure of veterinary practices had an influence: "*If I don't do it this way, another veterinarian will come along and do it the way the farmer wants it.*"

Interviewed veterinarians sometimes assumed that farmers wanted antimicrobials with short withdrawal times: [V4] "*We mostly use broad-spectrum antimicrobials in the teat instead of penicillin* [when treating gram-positive mastitis cases]*, as the withdrawal times are shorter […] We think that is what the farmer wants […]. We probably use more broad-spectrum antimicrobials than we should.*" This same dilemma was handled differently at another practice: [V10] "*Years ago, some farmers disliked Carepen* [benzylpenicillin procaine] *due to the six-day withdrawal time for milk. We just told them that they had to settle for systemic treatment only if they didn't want Carepen. It makes no sense to use broad-spectrum antimicrobials in these cases* [mastitis cases with gram-positive bacteria]*, we will not do so.*" As in this example from V10, most of the interviewed veterinarians generally did not believe the farmer influenced their AMU choices. V3 had only once experienced pressure to prescribe from a farmer, which she tackled by telling the farmer a lie: "*There was a product on the market that was attractive as there was no withdrawal time for milk […] and could be used for many things. The farmer wanted to use that, so I just told him that this product had been banned. I use tricks like that. He is probably the only farmer pressuring me about my AMU choices.*"

More often, farmers influenced veterinary AMU indirectly through their level of management. This was explained by V2: "*I think that if some farmers actually called their veterinarian and followed up on their sick animals, we could avoid changing to broad-spectrum antimicrobials* [due to undiscovered progression of disease] *and instead just extend the treatment with narrow-spectrum antimicrobials.*" The fact that farmers were bad at following up on treated animals often forced the veterinarian to prescribe other antimicrobials than first intended. This management factor was related to the other contextual factor in Section 3.1, i.e. farm-specific conditions.

Interviewed veterinarians approached these farmer preferences differently. As in the examples above, the veterinarian could be confrontational (V10) and not accept these preferences if they were perceived as scientifically incorrect, regardless of the consequences. Another approach was to be "manipulative" by telling a lie (V3). Some veterinarians also described "nudging" as a way to slowly change the farmer's attitude and preferences. This was perceived as a trade-off between not wanting to dissatisfy the farmer but still wanting to comply with scientific standards. This was described by V9: "*I know that farmers sometimes use antimicrobials in a careless manner. If they have a cow that limps, or a cow that looks unwell, they have attempted to treat her for pneumonia*[1]*. I don't confront them because I doubt it will have a positive effect to start arguing with them. It will just create a division in our relationship. Instead, I would rather nudge them* [nudging understood by the veterinarian as slowly introducing his own perspectives over time by continuously returning to the discussions on AMU]."

Many of the interviewed veterinarians emphasized the importance of establishing trust in their relationship with the farmer: [V2] "*It is very much about chemistry when you arrive as a veterinarian. […] I can change their attitude if I gain their trust, for example by helping them in some acute situation – a difficult birth, for instance […] or if they get the feeling that I am making an extra effort to help them. That way, you slowly build a relationship… But it really takes a long time to do.*" This established and ongoing bond was perceived as a prerequisite for changing farmer behavior or attitudes, and according to V5, farmers generally had a great level of trust in the veterinary profession: "*We have a large responsibility as veterinarians – we are the ones who can bring about change at these herds. The farmers are so faithful to us; what we say is the truth and they trust us to a high degree – at least if you manage to have a good relationship with your farmers.*" Furthermore, to be able to change anything within the collaboration, all of the interviewed veterinarians emphasized the importance of taking a farmer-specific approach, where the farmer's own perception of his issues became the starting point. This was exemplified by V12: "*I take a farmer-specific approach, I happily adapt according to the farmer. To be honest, that also helps to keep the farmers as our clients. […] Then, on days where the farmer actually has time to think about changes, […] I ask him questions like what he himself perceives as the biggest problem at the farm, what makes him happy in his daily life and so on. […] You would be surprised by what farmers are motivated by.*"

In this second theme, the interaction between individual and contextual factors in relation to AMU choices was illustrated. The contextual factor of experienced pressure from colleagues and farmers was intertwined with other contextual factors (i.e. the interviewed veterinarians' level of working experience and the structure of veterinary practices) and individual factors (i.e. feelings related to causing dissatisfaction among farmers or colleagues).

Current legislative and agricultural framework and room for maneuver in relation to antimicrobial use

As part of the Danish legislative structure, the Danish Veterinary and Food Administration was mentioned by many of the interviewed veterinarians as influencing and directing veterinary AMU due to their controlling and supervising actions. Supervision of practicing veterinarians had changed some of the interviewed veterinarians' AMU choices, as explained by V4: "*Being supervised by the Danish Veterinary and Food Administration greatly increased my motivation for changing my use practices. When they come and ask "why do you use this type of antimicrobial?", that makes me change.*" Some interviewed veterinarians used the limit given by the Yellow Card

[1] Danish farmers are only allowed to treat certain diseases independently.

initiative[2] to describe and justify the AMU level at herds with a veterinary agreement, i.e. if the AMU level was below the defined limit, it was perceived as an acceptable level. V3 suggested that veterinarians could be motivated to change their AMU if they were benchmarked against other veterinarians' AMU levels, as they take pride in having a low AMU level at the herds they service.

New Danish legislation was introduced in 2006, allowing conventional farmers to have medicines available at the farm for treatment of certain diagnoses. Previously, the veterinarian had to initiate all medical treatments. Many of the interviewed veterinarians expressed concerns about the shared responsibility of AMU between farmers and veterinarians as introduced by the current legislation. [V3]: "*I see it as a shared responsibility. I feel very responsible for the AMU level in the herds with which I have a veterinary agreement. It is not only because I could receive a fine of 5,000 DDK* [~ 800 USD] *if they* [Danish Veterinary and Food Administration] *find something […]. That doesn't keep me awake at night, but I do think about it a lot. Especially because some of my herds use antimicrobials differently from what I would prefer. I wouldn't terminate our agreement… but it does make me feel uncomfortable.*" In relation to that, the difficulty in balancing the dual role of being an enforcer of legislation and at the same time the farmer's collaborator in terms of veterinary consultancy was described by many of the interviewed veterinarians. V1 exemplified this: "*I know that many of my farmers don't comply with the rules for what they are allowed to treat. They don't tell me, but I can sense it. […] But what can I do? I am not there when it happens. […] I can check if the cows have actually recovered, but I can't really act more as a police officer than that. You cannot demand more from practicing veterinarians – we also need to be able to go there once a week. We can't do that if we start berating the farmer.*"

The interviewed veterinarians had different views on how the liberalization of medicines had changed farmers' AMU since its introduction in 2006. Some veterinarians were of the opinion that farmers had insufficient theoretical knowledge to handle antimicrobials independently. V3 described this: "*[…] We are not handing out sweets! It is crazy that we can expect farmers – not that they are unintelligent or anything, but they haven't received any training in diseases, anatomy, or pharmacy… They only know how the animal looks from the outside… To say, "Here you go! Now you are the veterinarian for your own herd, you can easily do that! I'll write you instructions of what to give them!" That is crazy!*" According to V3, this lack of knowledge had resulted in a suboptimal use of antimicrobials among farmers. V9 described this issue as a certain AMU culture: "*Some farmers lack knowledge – that is for sure. Another part is due to economics […] They don't want to spend money on a veterinarian, and they don't know what is wrong or how to fix it – then it's easy to just try something* [medication]*. That culture is getting worse by the year. […] It is just the attitude within farming – that this is how you do it.*" Other veterinarians believed that the liberalization of medicines had resulted in a better alignment in the need for and use of treatment among farmers. This was explained by V7: "*At the beginning, farmers were very excited about having medicines at their farm, but after a while, their relationship with medicines changed. They realized that medicines were not always the solution […] Although they had the medicines, they didn't necessarily use them.*

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[2] A politically defined limit for AMU (two times the national average consumption) in cattle, introduced in 2010. If the limit is exceeded, the farm will be subject to extra control visits by both the herd veterinarian and the Danish Veterinary and Food Administration, paid for by the farm.

[…] Nowadays, when a farmer has a case of mastitis, he can take a milk sample and wait for the results before initiating treatment. That wasn't the case back in the day, when the veterinarian was called and expected to initiate the treatment while they were there."

The interviewed veterinarians that had experienced the liberalization of medicines and the accompanying regular veterinary visits described how it had changed their role at the farms. This was exemplified by V8: "*Back then, we only went to a farm to treat and then left again; we had stagnated* [as a profession]. *Nowadays, we take a different approach – we look at what the problems are and what we can do to solve them.*" Frequent visits were thought to enhance knowledge about the farms and the familiarity with the farmer, thereby increasing the chance that the veterinarian would be able to assist in solving farm-related issues. However, for many interviewed veterinarians, the current legislation created a feeling of apathy in their work at herds when the situation deviated from their own standards. [V4]: "*In some herds, you just give up. You end up focusing on fulfilling your duties according to legislation and nothing more. Then I remind myself that it is actually not my responsibility if he doesn't succeed.*" This feeling of apathy – expressed by V1 as being a "factory worker" – could also result from the many routine tasks that legislation dictates must be completed in relation to herd visits. As explained by V5, these routine tasks are time-consuming, thereby taking surplus energy and focus away from important farm health and AMU problems. Furthermore, these routine tasks were not something the farmer (or the veterinarian) had any influence over, thus decreasing the feeling of ownership of the advisory agreement and their motivation in general. [V5] "*The fact that many things are decided by law implies that many things are done the way legislation dictates. That means that the farmer does not make an active choice about what he wants us to do, and we are lacking an alignment of expectations in that sense.*" V3 described legislation as a "duvet" covering both farmers and veterinarians from above and determining their range of actions. At the same time, the current legislative framework was also perceived as an important factor in preserving AMU levels and animal welfare in cattle farming by many of the interviewed veterinarians. V13 described this: "*No doubt that some farmers could manage without legislation – veterinarians would remain an important collaborator for these herds. However, we would also have a percentage of farmers who do not perceive veterinarians as collaborators – those we would lose* [the veterinarian would not visit regularly]*, and we wouldn't know the animal welfare standards at those herds.*"

In relation to this, many interviewed veterinarians suggested that farmers should only have narrow-spectrum antimicrobials available at the herd. This was perceived as a way to better synchronize the farmers' rights to handle antimicrobials independently and the veterinarians' law-enforcing obligations to ensure prudent AMU at farms. V9 explained this: "*Penicillin is the only antimicrobial farmers should be allowed to handle. Penicillin is sufficient in many cases – and in cases where it is not, the farmer should call for assistance. One could hope that such an approach would result in more cases being given a better scientific assessment before treatment.*"

This third theme mostly concerned the influence on AMU from contextual factors such as supervision by authorities and legislative structures that framed and influenced the veterinarian-farmer collaboration.

Resistance is rarely encountered on a daily basis but remains an abstract threat overshadowed by animal welfare concerns

AMR was considered indirectly through the interviewed veterinarians' choice of antimicrobials (type and amount) and the focus on preventing disease, and was not considered to be a factor in their daily lives, as explained by V9: "*I do not think a lot about resistance itself. I have a fundamental position that a cow without an infectious disease shouldn't receive antimicrobials. However, if she has an infectious disease, she should receive all the antimicrobials needed. Without thinking directly about resistance, it is of course indirectly a part of that basic attitude; not because I encounter resistance, but because I believe it's scientifically correct.*" For some veterinarians, justifying a certain choice of antimicrobials to the farmer was one of the few situations in their daily lives where they considered AMR: [V2] "*I think about it* [AMR] *when I need to discuss my choice of antimicrobials with the farmers. Then it hits me: I need to justify my choice, explain why I do what I do, tell them that there is no need to use broad-spectrum antimicrobials when we know this* [penicillin] *will work, and that we can potentially develop resistance if we do so.*"

The interviewed veterinarians had different perceptions about the extent of AMR in the herds they serviced. According to V11, single cases of AMR could be encountered in one animal, but never at farm level: "*We do not have local issues with resistance toward certain groups of antimicrobials. There can be single cases where a certain antimicrobial is ineffective, but then it works the next time and causes no further concerns. So I do not have the feeling that we have any resistance issues in Denmark, also based on the way we have used antimicrobials over time.*" V10, on the other hand, described a single case of farm-level resistance among calves with diarrhea, which after testing for susceptibility, could only be treated with Cobactan (Cefquinome). He made a connection between the farmer's AMU practices and the development of resistance: "*He is one of those farmers with an excessive use of antimicrobials. It is getting better and they have started to change their approach* [to AMU]. *The problem is that he would rather treat one time too many, instead of one time too few. Or even two times too many.*" In that sense, having an excessive use of antimicrobials was linked to a higher risk of developing resistance.

Some veterinarians mentioned that to their knowledge, other countries had bigger issues with AMR compared to Denmark. V13 explained this: "*I don't think about AMR as such. In Denmark, we have come a long way by only using penicillin for a long time. If you asked an Italian if he had concerns about the AMR problem – or a Dutch person for that matter – I think their answer would be different. Even though they have also come a long way.*" V5 had a similar opinion and expressed concerns that the restrictions on AMU could escalate and hamper competition in relation to the export of meat and dairy products: "*I think we need to continue as a pioneering country in relation to AMU, but we should also be careful not to put ourselves out of business. […] If there comes a point when we are only allowed to prescribe narrow-spectrum antimicrobials, should we then put animals down if they don't recover? […] I think that if additional restrictions continue to be added, we will end up having so many that we hinder ourselves in terms of the export market.*" Besides concerns about competitiveness, many of the interviewed veterinarians also mentioned compromised animal welfare as a result of restrictions on AMU. This was explained by V11: "*The balance between reducing AMU and animal welfare is very delicate. Or not delicate, but actually very fluid.*

The question is when is it responsible to stop treating with antimicrobials when it comes to animal welfare? What is most important?" Furthermore, animal welfare was seen as being difficult to measure as people often have individual opinions on what constitutes good animal welfare, which further complicates the evaluation of whether welfare standards are met. However, we found that all the interviewed veterinarians consistently expressed the opinion that sick animals have the right to receive medical treatment due to welfare concerns.

Organic farming was mentioned by some of the interviewed veterinarians as an example of pioneering farmers within the area of AMU reduction: [V11] "*Organic farming has a goal to reduce antimicrobial usage, which has influenced the way organic farmers think and work. That focus and consciousness about AMU has made organic farming stronger and more visible.*" However, organic farming was also mentioned as an example of a type of farming that had encountered issues in relation to the animal welfare dilemma described above. This was explained by V8: "*I like the thinking within organic farming – that they want to reduce their AMU, that they want to get away from this standard treatment approach to disease. But then you need to take preventive measures so that they don't get sick in the first place. […] And when you have a sick cow, you need to treat it. It makes no difference to only treat the cow once.*" Some interviewed veterinarians connected this resistance to treat for more than one day to the rules in force in organic farming, i.e., the requirement for veterinarians to perform all treatments. That would result in high economic expenses in relation to treatment and could discourage farmers from finishing the recommended course of treatment.

Within this fourth theme, individual and contextual factors collectively influenced the perception of AMR and hence the need to reduce AMU. Individual factors such as experiences with resistance and attitudes towards AMR were intertwined with contextual factors such as market forces, AMR levels in other countries and different types of farming that had different starting points and agendas in terms of AMU reduction.

Discussion

This qualitative study found that Danish veterinarians are influenced by a variety of interacting individual and contextual factors when prescribing antimicrobials. To our knowledge, this is the first study to investigate perceptions of AMU and current practices among veterinarians from a context of average-low level AMU where legislation on AMU has been implemented for decades. In the following section, central findings will be discussed in an attempt to explain some of the factors affecting the dynamics of veterinary treatment and prescription as described by the interviewed veterinarians.

One of the central findings of this study was that the AMU choices of newly educated veterinarians were influenced by their colleagues and farmers. As mentioned in the introduction, this contextual factor was also identified in the study by Higgins et al. (2017). However, the UK veterinarians explained their inability to oppose farmers' preferences through a combination of individual and contextual factors: a general lack of time to gain experience and knowledge from colleagues lowered their chance to increase their confidence in their own abilities and thus gain trust from farmers. Trust was, in their opinion, a prerequisite for going against the farmers' preferences. The influence from farmers (and colleagues) was experienced slightly differently in our study. First, some of the interviewed veterinarians identified fear as one of the primary drivers for complying with farmers' and colleagues' wishes and preferences. For example, in terms of antimicrobial therapy choices: for some of the interviewed veterinarians, it was the fear of losing the animal if the therapy should fail, for others it was the fear of being blamed (by the farmer or colleagues) for the therapeutic failure, and for others, the fear of being dismissed from their job. This fear-driven compliance with preferences of social referents has previously been described among veterinarians (Gibbons et al., 2013; Speksnijder et al., 2015a). Second, the young veterinarians we interviewed experienced a discrepancy between the theoretical, evidence-based knowledge of prudent AMU choices they were taught at university and the reality they faced in their first practice job. Therefore, for newly educated Danish veterinarians, social influence from farmers and colleagues was interconnected with individual factors such as personal feelings of fear and confusion about the prudent use of antimicrobials to treat animals. This confusion might have diminished their confidence in their own knowledge. Edmonson and Lei (2014) suggested that confidence in one's own knowledge was an important prerequisite for psychological safety (i.e., not feeling fear) and for taking interpersonal risks (i.e., arguing against or opposing farmer preferences). The importance of knowledge in relation to self-confidence was similar for UK and Danish veterinarians, but the skepticism towards the knowledge embedded in practice, i.e. the way their colleagues administered antimicrobials based on personal experiences, was unique to the Danish veterinarians in this study.

Some of the interviewed veterinarians with more experience expressed a similar skepticism towards the way personal experiences guided veterinary AMU choices. They were of the opinion that it was due to a lack of scientific evidence applicable to a local farm context. It therefore seems important to address the contextual factor of a lack of scientific evidence to diminish the social influence from farmers and colleagues that newly educated veterinarians experience. If they find that their colleagues base their AMU choices on herd-level evidence, they might experience a better alignment between their own choices (based on the evidence-based approach they were taught at university) and the choices made by their colleagues. That way, newly educated veterinarians will have greater self-confidence in their own knowledge and AMU choices, thus feeling safer to oppose farmers' preferences if these differ from "best practice". Studies have previously identified the need to use an evidence-based approach at herd level and the need for field-generated research on AMU and AMR that is applicable to veterinarians in a local farm context (Proctor et al., 2011; Lastein, 2012; Guardabassi et al., 2018). Furthermore, as requested by the interviewed veterinarians from this and previous studies (De Briyne et al., 2013; Speksnijder et al., 2015a; McDougall et al., 2017), objective and effective diagnostic tools should be developed to aid this evidence-based change in veterinary treatment and prescribing culture. To summarize, the contextual factor of social influence on veterinary AMU choices appears to be interconnected with a knowledge gap between theory and practice due to a lack of locally applicable evidence-based research. This knowledge gap affects newly educated veterinarians' confidence and trust in their own knowledge and AMU choices and thus their courage to resist or argue against farmers' and colleagues' experience-based and potentially biased preferences.

Another central finding of this study was the multiple reactions within the veterinary profession to increased legal control, i.e., regular supervision, lists of antimicrobials that cannot be used, the yellow card limit, the liberalization concerning farmers' use of medicines and, as a consequence, the predefined content of veterinary herd health visits. These different legal actions all comprise contextual factors influencing veterinary treatment and prescription under Danish conditions. As expressed by the interviewed Danish veterinarians, the feeling of self-determination in veterinary work has decreased, and thereby also the responsibility and motivation for addressing suboptimal AMU within herds, creating a feeling of hesitancy or apathy on a personal level. However, the regular supervision and control by the Danish Veterinary and Food Administration increased some of the interviewed veterinarians' motivation to change their AMU choices. As such, the contextual factor of legislation interacted with individual factors such as personal feelings of motivation and self-determination in both a positive (increasing motivation) and negative direction (decreasing motivation). It seems as though the influence from legislation could at times be so determining that it left no space for individual motivation for action among the interviewed veterinarians. In contrast, legislation could also force the veterinarians to change their behavior when confronted by the authorities about their AMU choices. Few other countries have experienced the same level of legal control of AMU, with the possible exception of the Netherlands, where similar legal approaches have been taken, though private industry parties mainly drove these initiatives. The self-motivated and voluntary approach with the government acting as a facilitator was highlighted as a way to ensure a sustainable reduction in AMU, as opposed to enforcement through legislation (Speksnijder et al., 2015b). The fact that legislation has been forced upon Danish veterinarians for decades might provide an explanation for the hesitancy and reduced motivation expressed among some of those interviewed. The interaction of legislation and motivation within veterinary herd health consultancy work should be considered carefully when planning future regulations in Denmark as well as in other countries.

One aspect of the contextual factor of legislation in particular, i.e. the liberalization of medicines in 2006, influenced the interviewed veterinarians' AMU through a complex pattern. The interviewed veterinarians felt responsible for ensuring prudent AMU, but the ability to live up to this responsibility was complicated by the fact that they were no longer involved in the daily decisions about AMU at the farms. Instead, they acted from a distance, i.e. only through prescribing medicines. Previous research shows that being allowed to handle certain medicines has made some farmers much more self-reliant (Skjølstrup et al., 2021), and the interviewed veterinarian of our study supported this finding by insinuating a certain culture of suboptimal use of antimicrobials among some farmers. The interviewed veterinarians therefore felt decoupled in terms of knowledge of and influence over the treatments at the farm. The obligation to ensure prudent AMU forced them into a dual role of a "police officer" with the responsibility to control the farmer's AMU, while at the same time being a close advisor and collaborator. The complexity in having both a controlling and advising role at farms has also been identified among Dutch veterinarians working under similar restrictions (Speksnijder et al., 2015a; b). When adopting the role of "police officer", an imbalance in power appears between the veterinarian and the farmer, and according to Noe et al. (2015), this might lead farmers to try to resist being pushed in the "right direction", and veterinarians might experience little success in changing farmers' AMU practices. The interviewed veterinarians of this study appeared to handle this "police officer" role through "nudging" and farmer-specific approaches in combination with a focus on a good and trusting relationship with the farmers. In some cases, this approach seemed to have replaced the confrontational approach, where violation of the veterinarians' professional standards or regulation resulted in boundary-setting.

It seems that veterinarians could clarify and communicate when they are adopting the role of "police officer" with an obligation to set boundaries, and when they are the advisory herd veterinarian with the farmer's interests in mind. Some of the interviewed veterinarians indicated their success in making the farmer aware of these dual functions; they welcomed legislation as a way to control farmer AMU without them being perceived as directly responsible for remarks on the required reduction in AMU. Another solution to this problematic dual role, as suggested by some of the interviewed veterinarians, was to tighten the legislation by allowing only penicillin to be administered by farmers[3]. In that way, the interviewed veterinarians believed their sense of responsibility in relation to the farmer's AMU would be more relaxed, as there would be a limit to how antimicrobials could be irresponsibly administered at the farm. This solution would thus be adding an "additional level" to the complexity within the contextual factor of legislation. To find the right balance of national legal control, future research should further investigate the implications of extensive AMU legislation on e.g., veterinarians' motivation in their advisory work in relation to reducing AMU at their affiliated farms.

Another central finding of this study was that the interviewed veterinarians perceived AMR as a distant threat that they automatically managed through their legally determined restricted use of antimicrobials. Furthermore, animal welfare concerns and acutely diseased animals could sometimes overshadow the threat of AMR. A similar perception of AMR as something distant and often overshadowed by daily concerns has previously been identified among cattle veterinarians and farmers (Golding et al., 2019; Skjølstrup et al., 2021). The reason that veterinarians perceive AMR as a distant threat could potentially be explained by the complex nature of the AMR crisis. Chandler described how the risk of AMR is difficult to define and measure, and it has often been framed as a future "hypothetical" threat that, despite lacking accuracy, requires urgent action (2019). Therefore, the risk of AMR can be difficult to comprehend. For veterinarians, action is not straight-forward because AMR is complex and entangled with e.g., emotions and everyday decisions about treatment and welfare issues, which is why distancing oneself from the "hypothetical" future risk can be seen as a natural reaction.

Blaming others was also identified among the interviewed veterinarians, but in a slightly different way to that identified and described in previous studies, where the need for inland reduction of AMU was broadly in focus and acknowledged (Speksnijder et al., 2015a; Golding et al., 2019). Being part of a low-AMU country had influenced the self-image of some of the interviewed veterinarians in this study, implying that they believed they were in a "safe space" and were therefore less obliged to change their prescribing practices and reduce their AMU further. Instead,

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[3] New Danish legislation was introduced in June 2021 allowing only narrow-spectrum antimicrobials to be used in the treatment of mastitis (with exceptions when diagnostic requirements are met).

it was perceived as more urgent that other countries adopted similar approaches to Denmark and demonstrated AMU reduction. Thus, the individual perception of AMR as a risk was intertwined with AMR being an abstract threat that is difficult to comprehend and contextual factors such as being part of a low-AMU country and rarely encountering AMR in everyday practice.

Chandler described how the framing of the AMR crisis has changed into a perception of a global issue that requires a multi-sectorial approach, as opposed to the previous perception of a few responsible actors who must individually change their behavior in order to "solve" the issue of AMR (2019). According to Chandler, acting on the AMR crisis can be considered a political "investment" (2019), and the extensive legal control on AMU in Denmark can be seen as an example of this. However, the contextual factor of legislation had an equivocal influence on the interviewed veterinarians' prescribing behavior. The veterinarians perceived their AMU behavior as rational because they complied with legislation and official guidelines. At the same time, other countries' relatively higher levels of AMU seemed to induce an abdication of responsibility among the interviewed veterinarians in terms of reducing their own AMU further. As such, individual factors of engagement and motivation for further reduction seemed to diminish with a high level of legislative control. This illustrates how the AMR crisis and the required reduction in AMU can be framed and decided at a societal level but perceived differently at an individual level, thus resulting in unexpected reactions, i.e., hesitancy among the veterinary profession. Therefore, as emphasized by Chandler (2019), the future discourse on AMR should include perspectives from all levels to offer a multi-sectorial approach that resonates with all actors concerned. If the global and complex issues of AMR (i.e., consequences for the global economy and human and animal health, conflicts that veterinarians face in their daily lives when trying to change AMU, and the collaborative effort that is required) are acknowledged and articulated, veterinarians might perceive the AMR crisis as being of closer personal relevance and may maintain their motivation to act upon it (Magalhães-Sant Ana et al., 2017).

Limitations

The first author was primarily engaged in the coding and analysis process, thereby ensuring alignment and consistency across non-verbal impressions during interviews and analysis of the transcribed interviews, although this could also be seen as a limitation of this study. Social-desirability bias could be suspected in an interview study concerning AMU as it can be a sensitive topic intertwined with multiple personal feelings and interests. However, interviewees shared AMU practices of which they were not proud, indicating that such a bias was largely not encountered in this study. Qualitative research is not intended to be generalizable, and the findings of this study arguably depend on their context. The UK, for example, has not seen the same level of state dominance through legislative control and influence over the veterinary profession (Hobson-West and Timmons, 2016). However, we argue that by describing the relatively low-level AMU context in which this study was conducted, the findings can form a basis for discussions and inform a hypothesis of influence from e.g., changing legislation in other similar national contexts.

Conclusion

We found that the AMU practices of interviewed Danish veterinarians' were influenced by individual and contextual factors in a complex and interactive pattern. The veterinarians were guided by personal experiences and emotions intertwined with the availability of local or general scientific evidence in relation to their AMU practices. In addition, we found that less experienced veterinarians felt pressured in their treatment and prescription choices from both their veterinary colleagues and farmers. Therefore, developing herd-specific evidence-based research on prudent AMU choices and objective diagnostic tools might align veterinarians' approaches to AMU and empower newly educated veterinarians in their prescribing behavior. Furthermore, we found indications that the extensive legal control related to AMU introduced some challenges to the Danish veterinary profession in the form of decreased motivation in their advisory work and the dual role of being a legal controller and an advisor at farms. Veterinarians could explicitly communicate this dual role as "police officer" and close collaborator at farms in order to overcome obstacles in the farmer-veterinarian relationship that might otherwise hinder a fruitful collaboration to reduce AMU. Lastly, we found that some of the interviewed veterinarians did not perceive AMR as an everyday threat that required their sustained attention, and the discourse on AMR might therefore need to be reframed, taking into account all concerned actors and the full complexity of the issue.

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Appendix

Table 3 Coding tree

Danish cattle veterinarians' perspectives on antimicrobial use: contextual and individual influencing structures		
Selected meaning condensates and examples of statements	Codes	Themes
No broad-spectrum antimicrobials for *E. coli* mastitis ("*I was raised to treat these cows with broad-spectrum antimicrobials, but we have recently discussed trying to start the treatment with narrow-spectrum antimicrobials and supportive therapy.")* No treatment of mastitis before diagnostic result is ready Should be based on science but is often based on personal experiences instead	"Correct" approach to treatment	Personal experiences and the availability of medicines guide everyday treatment decisions
To use diagnostics properly Setting standards for AMU	What is perceived as important	
Difficult to change treatment pattern when accustomed to something Difficult for experienced and older veterinarians	Changing habits	
Courses and experts Colleagues Clinical experiences (own and others) Local evidence as opposed to general evidence	Influencing factors	
More objective diagnostic tools More local evidence produced	Wishes	
Some veterinarians are busy and do not prioritize diagnostics Older veterinarians have been used to having all antimicrobials available	Attitudes toward other veterinarians	
Some farmers know what antimicrobials they want, others let the veterinarian decide Some farmers want quick answers and action	Attitudes toward farmers	Social relations and diverging interests influence AMU practices
Not letting the farmer determine the veterinarian's AMU Delivering results, changing farms Retaining clients	What is perceived as important	
The condition of the cow The farmers' wishes and preferences (*"For some farmers, the antimicrobials just need to work and have as short a withdrawal time as possible".)* Colleagues' choices Traditions	Influencing factors	
Some veterinarians break the law to retain their clients Some veterinary practices teach their employees bad AMU habits	Attitudes toward other veterinarians	
Some farmers only want the veterinarian to perform the tasks determined by legislation (*"Some farmers just want you to come and do your job. They perceive me as a*	Attitudes toward farmers	Current legislative and agricultural

legislatively determined measure. I only need to do the things required by law.") Some farmers break the law		framework and room for maneuver in relation to AMU
Balancing dual roles Liberalization of medicines is bad for AMU and animal welfare	Attitudes toward advisory services	
Must regulate our AMU Outlines what veterinarians can force farmers to do A necessity	Attitudes toward legislation	
Complying with legislation Being below official limits for AMU	What is perceived as important	
More control over farmer's treatment Adjusting the official limits for AMU	Wishes	
Affected by benchmarking in relation to AMU Some veterinarians run on routine due to legislation	Attitudes toward other veterinarians	
Worse in other countries (*"You can get quite frustrated; we do a lot of good things in Denmark, but you just need to cross the border… we know that the AMU levels are completely different there.")* Primarily in relation to cows, not humans	Attitudes toward AMR	Resistance rarely encountered on a daily basis – remains an abstract threat overshadowed by animal welfare concerns
Farmers Both farmers and veterinarians	Responsibility for AMU	
Always use narrow-spectrum antimicrobials if there is a documented effect When first initiated, continue treatment for a long enough duration Sick animals need treatment	"Correct" approach to treatment	

9.4 Manuscript IV

A mixed methods approach to monitoring changes at Danish dairy farms during a veterinarian-facilitated Stable School to improve health and antimicrobial use

Nanna Krogh Skjølstrup,[1*] Anders R. Kristensen,[1] Leonardo V. de Knegt,[1] Liza R. Nielsen, Dorte B. Lastein,[1]

[1]Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, 1870 Frederiksberg C, Denmark

*Corresponding author: Nanna K. Skjølstrup, Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, Grønnegårdsvej 2, DK-1870 Frederiksberg C, Denmark. Email: nannaks@sund.ku.dk.

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Abstract

The objectives of this study were to investigate the potential for a veterinary-facilitated Stable School to instigate changes in antimicrobial use (AMU) on participating farms and to demonstrate the application of a mixed methods approach to evaluate changes in treatment risk and milk yield. Five conventional dairy farms participated in a Stable School with the overall goal of "Improved health – fewer antimicrobials" for 1 year. Data on individual cow milk yield and treatments from 3 years before and until the end of the Stable School period were collected for all farms, and state space models for monitoring treatment risk and milk yield were developed. All Stable School meetings were observed by the first author using a complete observer approach. Two semi-structured interviews were conducted with each of the participants and the primary facilitator. Qualitative and quantitative data were analyzed retrospectively and combined using triangulation in a parallel data analysis. All participating farms underwent changes during the Stable School period, including structural changes such as adjustment of cubicles or application of teat sealers as well as non-structural changes such as changed attitudes, increased work experience and self-confidence. Farm-related barriers such as lack of employees and the Stable School facilitation approach seemed to influence the outcome of participation. At the end of the Stable School, quantitative monitoring graphs showed no change in treatment risk relative to the starting point in any of the herds. In addition, we observed various deviations in daily milk yield levels (150 to -500 kg energy corrected milk relative to the herd's baseline average yield). Triangulation illustrated that qualitative data are valuable for an in-depth understanding of observed changes in quantitative data, providing a more complete basis for conclusions about the potential for Stable Schools to instigate changes. Despite the small decrease in treatment risk, the Stable School provided a safe and reflective platform for participants to instigate changes. An explicit focus on AMU, balanced Stable School facilitation and common goalsetting at meetings might enhance the outcome in terms of reducing AMU.

Key words: Stable School, veterinary advisory services, antimicrobial use, dynamic linear model, mixed methods.

Introduction

Antimicrobial resistance is a growing global problem affecting both human and animal health (Laxminarayan et al., 2013; Tang et al., 2017). Authorities suggest that the use of antimicrobials should be reduced as much as possible without compromising animal welfare in livestock production (Murphy et al., 2017). Reducing antimicrobial use (AMU) includes minimizing the use and need of superfluous or inappropriate antimicrobial treatments. Therefore, a focus on disease prevention and an understanding of when treatment should be initiated or avoided, combined with close monitoring of the consequences of AMU reduction on health, welfare and production is central. Within the dairy cattle sector in Denmark, dairy farmers collaborate most closely with veterinarians in terms of AMU, and this sets the foundation for reducing AMU in dairy cattle. However, there has been no further reduction in overall AMU in Danish cattle over the past 5 years (Korsgaard et al., 2020). This could imply that alternative advisory measures might be needed in addition to the classical veterinary herd health consultancy (VHHC) framework with top-down expert knowledge transfer (Vaarst et al., 2007) that has historically framed the veterinarian-farmer collaboration format under Danish conditions. Reducing AMU at dairy farms could be driven by a motivated farmer, and previous research has shown that other farmers' practices, attitudes and success can motivate farmers to change their behavior (Vaarst et al., 2007; Swinkels et al., 2015; Skjølstrup et al., 2021c; a).

The Stable School is an example of an advisory concept that integrates this exchange of attitudes and experiences among farmers. It consists of a group of typically five to six farmers working towards a defined overall common goal over a 1-2-year period. They meet at regular (e.g. monthly) intervals at each other's farms to share experiences and solve farm-specific issues related to the overall goal. An external facilitator can be enlisted or the practicing herd veterinarian can take on this role. The facilitator must ensure sound group dynamics and equal opportunities for communication among participants, and not offer scientific advice during the sessions (Lisborg et al., 2005). Stable Schools could therefore be an opportunity for farmers and veterinarians to work collaboratively and effectively towards reducing AMU, and veterinary practices could offer them as an add-on or as an alternative to classical VHHC (Ministry of Environment and Food of Denmark, 2018). It has previously been shown that AMU decreased in Danish organic herds participating in Stable Schools compared to non-participating herds (Bennedsgaard et al., 2010). The Stable School concept has also been tested in a number of European countries with varying results in terms of treatment frequency (Ivemeyer et al., 2015). Furthermore, in the UK, Morgans made a few alterations to the original Stable School concept and demonstrated a reduction in Highest Priority Critically Important Antimicrobials (HPCIA) in 27 out of the 30 participating (mainly conventional) dairy farms (Morgans, 2019; Morgans et al., 2021). However, the potential for Stable Schools to promote a change in AMU in Danish conventional dairy herds has not yet been investigated.

Monitoring animal health, production and AMU in herds participating in a Stable School is useful for both the farmers and facilitating veterinarians, as seeing the results of successfully implemented interventions can increase the motivation to continue (Vaarst et al., 2007). State space models (SSMs) have previously been used to monitor different outcomes within dairy farming systems (Thysen, 1993; Van Bebber et al., 1999; Cornou et al., 2014). SSMs might therefore be useful in monitoring systematic changes resulting from Stable School-motivated interventions. SSMs incorporate systematic variation and confounding factors, as well as hierarchical and correlated structures present in the complex farm setting. Simpler data analyses or monitoring systems based on raw data rarely take these factors into account and the results are prone to misinterpretation (Krogh, 2012). Furthermore, SSMs are continuously updated as new data arrives, allowing for visualization of intervention effects and rapid decisions on whether to continue the intervention.

Information about interventions and changes made on the farms is required in order to make informed assumptions about the reasons or causalities between interventions/changes and observed fluctuations. This can be a difficult task as not all interventions will be promptly or explicitly implemented. A mixed methods approach to analyzing farm-specific changes through close qualitative and quantitative monitoring might therefore be relevant (Kristensen et al., 2008).

The present study has two objectives: first, to investigate the potential of a Stable School to instigate changes in AMU in conventional herds with a veterinary practice in the facilitating role; second, to combine qualitative and quantitative observations to illustrate and analyze changes in AMU treatment patterns and milk production retrospectively in farms participating in a Stable School. We chose to monitor two different exemplifying quantitative outcomes: treatment risk as a proxy for AMU and milk yield as a proxy for herd health and production, as there would be little interest in reducing treatment risk if it resulted in a large decrease in clinical herd health or production economy.

Materials and methods

The study complied with relevant Danish and International standards and guidelines for research ethics, and approval was granted by the Research Ethics Committee for Science and Health, University of Copenhagen (ReF: 504-0137/20-5000). Furthermore, the project complied with the rules of the General Data Protection Regulation and approval was granted (Ref. no.: 514-0312/19-3000). Results are reported in accordance with the COREQ checklist (Booth et al., 2014). Written consent to extract and analyze data from the Danish Cattle Database (DCD) was given by all participants of the Stable School.

Stable School: format, recruitment and participants

In March 2020, six Danish conventional dairy farms were recruited to participate in a Stable School by their local veterinary practice. To be included, the farms had to meet the following criteria: they should be conventional (e.g. non-organic production) and the participating farmer should preferably be the operations manager of the herd. A variety of Danish conventional dairy farms with different herd sizes, breeds, milking systems and production levels (Table 1) were represented. All farmers paid a participation fee of 8,000 DKK (approximately 1,200 USD) to their veterinary practice for the time spent facilitating the Stable School.

The overall goal of the Stable School was "improved health – fewer antimicrobials". One farmer from each farm participated, except for Herd 4, which had two participating farmers. In all but one case, the farmers were employed as herd operations managers. For Herd 3, the participating farmer had recently taken over the ownership of the herd. Two veterinarians facilitated the Stable School, and only the primary facilitator (Facilitator 1) had previous experience of facilitating Stable Schools. The facilitators had varying previous knowledge of and relationships with the participating herds (Table 1). The first Stable School meeting was held in May 2020, and the participants continued to meet approximately once per month until the last meeting in April 2021. Herd 4 withdrew after participating in two meetings, as one of the operations managers was injured and the other resigned. Furthermore, Facilitator 2 left the Stable School halfway through due to maternity leave.

Table 1. Descriptive data for farmers and herds enrolled in the Stable School as of May 2021.

Herd	1	2	3	5	6
Farmer age	34	27	24	30	22
Year employed at herd	2018	2016	2018	2017	2019
Number of cows	200	275	496	479	264
Breed	Holstein	Holstein	Jersey	Jersey	Holstein
Milking system	Milking parlor to AMS[1]	Milking parlor	Milking parlor	Milking parlor	AMS
Milk yield (kg ECM, annual yield, average per cow)	11,052	11,068	8,931	9,971	12,662
Somatic cell count (average for all cows on the last test day)	181	108	386	299	197
ADD per 100 animals per day (9 months rolling average)[2]	0.56	0.31	1.11	0.78	0.83
Facilitators' role at herd	No role	Facilitator 1: Substitute herd vet.	Facilitator 1: Herd vet.	Facilitator 1: Substitute herd vet. Facilitator 2: Herd vet.	No role

[1]Automatic milking system. [2]Country average: 0.60.

Qualitative methods

The first author (interviewer and observer) used different methods to identify herd-specific changes as part of the Stable School. The definition of change in the present study included concrete elements of change such as structures and practices, as well as more symbolic elements, i.e. non-structural changes such as understanding and assumptions (Finstad, 1998). Changes in perceptions, attitudes and discourse among Stable School participants were considered equally as valid as changes in management routines on the farms. Furthermore, we perceived change as part of a system, i.e. a farm system or Stable School, which can influence and potentially instigate change trajectories (Geels and Schot, 2007). This definition was considered as the change processes were identified and described during the data collection and analysis. Only changes initiated during the Stable School period were reported, i.e. the continuation of these changes or occurrence of new changes beyond the period were not evaluated. Qualitative semi-structured interviews with all participating farmers and facilitating veterinarians were conducted before initiation of the Stable School. All Stable School meetings were observed and telephone interviews with Facilitator 1 were conducted between all meetings. Lastly, individual interviews with all participants were repeated at the end of the Stable School (or at the time they left the Stable School in the case of Herd 4 and Facilitator 2). Semi-structured individual interviews were used as they allowed for an in-depth understanding of personal perceptions and experiences of change processes (Kvale and Brinkmann, 2014). We chose to observe the Stable School meetings to identify any changes in relations, discourse, actions, communication and expressed feelings among the participants of Stable School. Furthermore, the observations supported and enhanced the individual interviews.

Interviews

Prior to Stable School initiation, the first author reflected on her background (PhD student, previously practicing cattle veterinarian), the expected influence from previously conducted interview studies on AMU and expectations related to following the Stable School process, as well as discussing attitudes towards AMU with the participants. This allowed for uniform and transparent Stable School observation and interviews with the participants. The first author attended several courses with a partial focus on non-participant observations, and observed another unrelated Stable School meeting prior to this study to practice the techniques.

An introduction meeting was held in March 2020 to introduce the first author and purpose of the study, as well as the tasks and meetings the participants were expected to perform and attend as part of their engagement in the Stable School. No participant objected to the first author's participation. She had no previous relationship with any of the participants, but knew Facilitator 1 both professionally and personally. This relationship was acknowledged during the Stable School process.

Initial interviews were conducted in March 2020 and the final interviews in April 2021. All interviews lasted between 33 and 66 minutes (average 51 minutes), were conducted in Danish following an interview guide (Table 2) and were audio-recorded. Interviews were conducted at the interviewees' workplace in a quiet area without any disturbance. A consent form was signed by the interviewees, ensuring confidentiality and the ability to withdraw from the interview at any time before the data analysis was initiated, and permitting the interviewer to use the interviews for analysis. No participants withdrew their consent. The interviewees were encouraged to direct the course of the interview and were steered back to the themes of the interview guide when necessary. Any contradictory statements or uncertainties presented by the interviewee were clarified during the interview, and central statements were repeated by the interviewer and confirmed or corrected by the interviewee as they were presented. At the end, a summary of key points was provided so that interviewees could correct or add any new points. No interviews were repeated and no transcripts were returned for interviewees to make comments or adjustments. Notes on immediate impressions were made after every interview, and potential adjustments to the interview guide considered (none were made).

Table 2. Interview guides for the two interviews.

Interview guide – initial interview	Interview guide – final interview
- Motivation for participation (previous knowledge about Stable Schools) - Expectations (your role, the role of the other participants and the facilitators, results, concept) - Three specific issues you want to work on (description, expected outcome from Stable School, success criteria) - Challenges (what, how to address these) - Responsibility (who, how to comply) - Thoughts on AMU (correct use, specific example, purpose of Stable School) - Communication about change (with colleagues, veterinarian)	- How did it go? (Interviewees took and showed three pictures of a change resulting from the Stable School) - Motivation (development, status) - Results of the three specific issues (interviewer reminds interviewee of chosen issues) - Challenges (what, how did you address these?) - Responsibility (who, how did you address this?) - Thoughts on AMU (changes, status, purpose of Stable School) - Communication about change (how did it go?) - Suggestions for changes (what could have been different, future participation?)

Interview analysis

The final interviews were fully transcribed using a non-verbatim approach by the first author. The initial interviews were not fully transcribed but contributed to the results. Transcription was done using NVivo 12 plus software (QSR, International); an asterisk (*) was used to hide easily recognizable names, square brackets to provide extra information, and [...] to indicate where a quote had been shortened. All interviews were analyzed by the first author using a retroductive approach (Hartig, 2011), i.e. the definitions of change given in the introduction were the "theoretical" starting point for identifying elements of change in the available data. The definition was used to explore observed realities to identify and understand the complex mechanisms of change on the farms and in the minds of the participating farmers (Jagosh, 2020).

Observations of Stable School meetings

All Stable School meetings were observed using a complete observer approach, as described by Baker (2006). Nine meetings were held between May 2020 and April 2021 (two meetings at each herd, except for Herd 5). Table 3 provides an overview of Stable School events with individual meetings and qualitative data collection.

Table 3. Overview of meetings and qualitative data collected during the Stable School.

Year	Month	Events	Qualitative data collected
2020	January	Recruitment of herds by veterinary practice	
	February		
	March	3rd : Introduction meeting Herd 6 changes participant (farm owner to	Individual interviews: participants +

		operations manager) COVID-19 delays start of Stable School	Facilitator 1
	April		
	May	14th : meeting 1: Herd 6 (6 + 2)*	Observations of meetings and conversations with participants + interview with Facilitator 1 after each meeting
	June	10th : meeting 2: Herd 3 (7 + 2)	
	July	Herd 4 withdraws (due to new job)	
	August	6th : meeting 3: Herd 2 (3 + 2)	
	September	9th : meeting 4: Herd 1 (4 + 2) 30th : meeting 5: Herd 5 (5 + 2)	
	October	Facilitator 2 withdraws	Individual interview Facilitator 2
	November	Meeting cancelled (COVID-19)	
	December	Meeting cancelled (due to numerous cancellations from participants)	
2021	January	14th : meeting 6: Herd 6 (3 + 1)	Observations of meetings and conversations with participants + interview with Facilitator 1 after each meeting
	February	24th : meeting 7: Herd 2 (3 + 1) Herd 5 withdraws	
	March	10th : meeting 8: Herd 3 (3 + 1) 25th : meeting 9: Herd 1 (4 + 1) (evaluation)	
	April	Meeting cancelled (Herd 5 new job)	Individual interviews: participants + Facilitator 1
	May	Official end of Stable School	

*First number indicates the number of participants; second number indicates the number of facilitators present.

All meetings lasted approximately 3 hours and generally followed the agenda presented in Table 4. The host chose the herd-specific problems related to health/AMU to be discussed and a herd success story to present at a meeting with the facilitator(s) approximately 1 week prior to the Stable School meeting. A telephone interview was conducted with Facilitator 1 prior to the Stable School meeting to summarize this planning meeting and any observed changes at the herds since the last meeting.

Table 4. Agenda for Stable School meetings, inspired by "Staldskolehåndbogen" by Lisborg et al. (2005).

Meeting no., participant name and herd address, date and time

1. Welcome
2. Since last: status from previously visited herds
3. Introduction to farm by host (only for first round of visits)
4. Farm tour (approximately 1 hour)
5. At the table (approximately 2 hours)
   5.1. Break with sandwiches and open discourse

5.2. Host introduces a farm success
5.3. Host introduces two farm-specific issues: today's focus
For each issue:
5.3.1. Presentation
5.3.2. Question round(s)
5.3.3. Round(s) of suggestions for solutions
5.3.4. Host decides on what suggestions to try
6. Next meeting

Notes on impressions were taken during the farm tour, while notes taken during conversations at the table (point 5 of the agenda in Table 4) were supported by an audio recording. A self-reflective commentary with immediate impressions from the meeting was then recorded. Furthermore, a summary with a focus on changes observed in discourse, conversations, statements, actions, feelings or reflections was written based on the notes and audio recording. Short individual interviews with the host and Facilitator 1 were carried out after each meeting to capture their immediate reflections and experiences. A collective evaluation was performed at the last Stable School meeting. Thus, the qualitative data used in this study were based on individual interviews and observations, which were analyzed using the retroductive approach.

Quantitative methods – state space models

An in-depth description of the developed SSMs on continuous and dichotomous outcomes can be found elsewhere (Skjølstrup et al., 2021b). In short, a dynamic generalized linear model (DGLM) was developed for monitoring overall treatment risk (e.g. all treatments for perceived infectious diseases requiring antimicrobials), and a dynamic linear model (DLM) for monitoring daily milk yield was adapted from Stygar et al. (2017). The models were developed during the Stable School period and monitored the chosen outcomes retrospectively. Model assumptions were checked and deemed sufficient for monitoring purposes.

In order to monitor AMU, the weekly overall treatment risk (after first calving) was plotted as a proxy. We used daily individual cow treatments, which farmers and veterinarians are obliged to register in the DCD in our analysis, rather than the exact amount and type of antimicrobials used or weight-corrected measures. This included individual treatment of clinical and subclinical mastitis, metritis, retained placenta, infectious gastrointestinal disorders, infectious locomotor disorders, pneumonia, urinary tract infections and dry cow treatments. By using treatment registrations, the analysis primarily represents farm management choices in relation to the administration of drugs, and not the health status or a precise description of AMU on the farms. The model took into account the parity and stage of lactation of cows present in a given week. Furthermore, a random herd-level week effect was included, meaning that the risk of treatment was autocorrelated within the herd and that a high herd-level treatment risk would be expected if it had been high during the previous week. The treatment risk for the individual parities and different stages of lactation was assumed to be constant, whereas the week effect fluctuated, thus indirectly accounting for seasonal effects on treatment.

The milk yield outcome was monitored through test day information on individual cow milk yield, which is collected approximately 11 times annually and is available from the DCD. For the milk yield monitoring graphs, the sum of the aggregated individual cow production potential A_t and local production effect X_t per day from the DLM was plotted over the Stable School period, i.e. for each parity group (1, 2, 3+), the milk yield outcome was expressed as the deviation between daily herd-level milk yield and the modelled average daily herd-level milk yield (lactation curve) at the start of the Stable School. Plotting these model parameter estimates meant that systematic effects were taken into account, i.e. the cows' stage of lactation and parity, dependence between observations and individual cow fluctuations (seasonal effects were accounted for indirectly). The filtered results of both the treatment risk and milk yield model were smoothened to use all available data to evaluate the levels retrospectively in the four herds.

Herd 3 was excluded from SSM monitoring due to a change of owner during the historical data collection period and numerous missing registrations regarding dry dates. Therefore, the data consistency and validity were suboptimal for this herd.

Analytical approach to combining qualitative and quantitative data and methods – triangulation

The qualitative and quantitative methods and analytical approaches of this mixed methods study were combined through triangulation in a parallel data analysis at the interpretation stage at the end of the Stable School (Jick, 1979; Östlund et al., 2011). We were inspired by the approach of Östlund et al. to describe whether the results of the two individual analysis might be convergent, complementary or divergent when interpreted in combination (2011). For example, the monitoring graphs might indicate no changes in treatment risk or milk yield over time, yet individual participants might have the perception or personal experience that changes did indeed occur. In that case, the results would be divergent, however, one data source or result is not perceived as superior to the other in this descriptive analysis. Triangulation was performed to improve the reliability and validity of the overall farm conclusions and hence aid in decision making. The two types of data allowed the conclusions to be seen from a holistic perspective; they complemented each other by allowing for deeper or new dimensions to emerge. The qualitative information on changes (Table 5) is naturally limited by the fact that data on individual herds were only collected approximately once a month. The study set up did not allow for in-depth herd-specific knowledge on all potential changes (structural or non-structural), and the results of the triangulation will therefore not show the entire picture at the farms. Despite that, the approach serves as an example of how to gain more in-depth knowledge about herd-specific changes.

Results

This section presents the qualitative data followed by the quantitative data. This order was chosen to allow a thorough understanding of the five participating herds in terms of changes initiated, farm-related barriers to change, as well as the Stable School-related barriers to change as perceived by the participating farmers and facilitators, before an in-depth examination of specific farm numbers and how they relate to the identified changes.

Overview of changes in participating herds

The identified herd-specific changes (structural, non-structural and non-Stable School-related) are summarized in Table 5 alongside the specific qualitative data source of origin (interviews, observations, other participants or the facilitator). Examples of changes specific to the Stable School will be described in the following section for a thorough understanding of the mechanisms of change.

Table 5. Types of changes in the five herds participating in the Stable School. Qualitative source of results: (O) Observation, (I) Interviews, (P) Other participants, (F) Facilitator(s).

		Structural changes		Non-structural changes
Herd		**Stable School (SS)-related changes**	**Non-SS-related changes[1]**	**Changes in attitudes, perceptions, discourse, abilities**
1 (P1)	Mar		Year 2019: somatic cell count (SCC) of 300,000 – still with issues (I). Higher milk yield compared to 2019 due to changed milking times (I). Building new cow shed (I). Trying to engage employees (I)	
	Apr		Building new cow shed (I). Trying to engage employees (I)	
	May		Building new cow shed (reduced yield) (I). Trying to engage employees (I)	Withdrawn due to language barrier (O, I)
	Jun	Went to see Herd 2 (F)	Building new cow shed (I). Trying to engage employees (I)	Inspired and motivated by other herds (I)
	Jul		Building new cow shed (I). Trying to engage employees (I)	
	Aug	Use of teat sealer with DCT (if SCC >200,000 and positive bacteriological sample) (I)	Building new cow shed (I). Trying to engage employees (I)	Inspired by dry-off management in Herd 2 (I)
	Sep	Change of claw bath routines (lime water twice weekly) (I) Lime used more frequently in cubicles (I)	Building new cow shed (I). Trying to engage employees – sodas and coffee breaks (I). Milk production decreasing, higher frequency of metritis –> cows stressed (I)	More active role in SS (O)
	Oct		Building new cow shed –> cows stressed (I). Changing from milking parlor to AMS (claw bath routines halted for a period) (I). Change of employees (I)	Believes that use of teat sealers is a success (I)
	Nov		Building new cow shed –> cows stressed (I). Changing from milking parlor to AMS (I)	
	Dec		Changing from milking parlor to AMS – cows adjusting quickly (I + F)	
	Jan	Change in robot routines (collecting cows, spreading straw in cubicles) (I)	Cows adjusting (I). Claw bath routines initiated again (I)	Inspired by robot routines in Herd 6 (I)
	Feb		Far-off and close-up transition feeding initiated –> fewer milk fever cases (F). Milk yield decreasing and issues with udder infections in early lactation remain (F). P1	

			took a course in milk fever and metritis (I)	
	Mar	Change in cleaning procedures of milking equipment for fresh cows (I). Changing criteria for DCT (I). Focusing on cleanliness when applying DCT (I)	P1 primarily responsible for the cows – improved management routines (I). P1 course in milk fever and metritis (I)	Boss participated in SS – "*easier to pass on information to everyone on the farm*" (I). Believes that figures and numbers contain important farm information (I)
	Apr		Improved communication and collaboration between employees (I)	Believes that he is now more experienced in farming (I). Believes that claw bath routines are efficient (I). Believes that rapid intervention (treatment) helps recovery – cows that cannot be cured with treatment should not be treated (I)
2 (P2)	Mar		Lack of employees (I). Lack of space for dry cows (F)	Wants to inspire employees (I)
	Apr		Lack of employees (I). Lack of space for dry cows (F)	
	May		Lack of employees (I). Lack of space for dry cows (F)	Tired of introducing new employees (I)
	Jun		Lack of employees (I). Lack of space for dry cows (F)	Believes the SS meetings lack steering and structure (I)
	Jul		Lack of employees (I). Lack of space for dry cows (F)	
	Aug		Lack of employees (I). Spends time training new employees (I). Lack of space for dry cows (F) Planning to change from conventional milking to AMS (I). Slow change process at the herd (I)	Believes that changes are easiest to implement if they involve only her (O). Wants to install rubber mats to prevent claw lesions and make a section for dry cows in the shed to improve their space (I)
	Sep	Changing start of insemination to 60 days after calving instead of 40 –> extend calving interval and reduce no. of dry cows (I)	Lack of employees (I). Planning to change from conventional milking to AMS (I)	Frustrated that foreign employees do not respect her as their boss (I). Happy to see that other farms are in a worse condition (I)
	Oct		Lack of employees (I). Planning to change from conventional milking to AMS (I)	
	Nov		Lack of employees (I). Planning to change from conventional milking to AMS (I)	
	Dec		Lack of employees (I). Planning to change from conventional milking to AMS (I)	
	Jan		Lack of employees (I). Planning to change from conventional milking to AMS (I). Keeps cows in heat in separate area to avoid claw/leg injuries (I)	
	Feb	Investing in claw baths and lime for heifer area (I)	Lack of employees (I). Planning to change from conventional milking to AMS (I). Heifer area with compromised welfare – lameness and poor growth due to unorganized management (I)	Believes that the heifer area is not as bad as first perceived (I)

	Mar		Lack of employees (I). Planning to change from conventional milking to AMS – 3 robots, fewer cows required –> selling heifers (I). Claw baths have not been in use yet due to being busy (F)	Believes that heifer area issues will be solved by selling a large number of animals + using beef cattle semen to avoid overcrowding (I). Operations manager experiencing a stressful time (I)
	Apr		Lack of employees (I). Planning to change from conventional milking to AMS – August (I)	Believes that the lack of employees was the main reason for not changing much during the SS (I)
3 (P3)	Mar		Owners recently took over herd – herd health not stabilized (full SS period) (I). Issues with ketosis (I). New feeder and feeding strategy reduced occurrence of milk fever (I). Issues with pneumonia among calves (I)	Hopes to receive practical advice to optimize herd + gain experience (I)
	Apr		Issues with ketosis (I). Issues with pneumonia among calves (I)	
	May		Issues with ketosis (I). Issues with pneumonia among calves (I)	
	Jun	Improving ventilation in old calf shed (I) Shaving the calves' backs when they are disbudded (I)	Issues with ketosis – management changes for fresh cows (feeding, housing) (I). Issues with pneumonia among calves (I)	Changed perception of calf health from good to bad (F, I, O). Many different things have been tried with fresh cows, trusts own gut feeling more than other participants (I). Reluctant to change due to unstable herd health (O, I).
	Jul		Issues with ketosis (I). Visited by feed consultant: acidified feed for dry cows (I). Fresh cows moved to cleaner section in the shed (I). Initiated vaccination for calves (I). New calf manager employed (I)	Believes an effect was seen from feed adjustments (I)
	Aug		Issues with ketosis (I). Heat stress among cows (F)	
	Sep		Lack of employees (F)	
	Oct		Building new calf shed (I). Calves not vaccinated –> pneumonia (F). Lack of employees (F)	
	Nov		Building new calf shed (I). SCC under control (F). Lack of employees (F). Vaccination of calves (I)	
	Dec	Identification of cows with *S. aureus* and separation –> SCC decreased (I, F)	Building new calf shed (I). Allowed to slaughter 30 cows due to investment (F). Issues with calves – high mortality – changing type of antimicrobial (F). Vaccination of calves (I)	Inspired by Herd 6's approach of separating cows with *S. aureus* (I)
	Jan		Building new calf shed (I). Issues with ketosis (I)	
	Feb		Building new calf shed. Acute outbreak of mastitis cases, dead cows, peak in SCC and bacterial count due to new bedding material (I). Visited by milk consultant (F). Area renovated for fresh cows and separation (I)	Glad that other participants confirm own thoughts on calf management (I)
	Mar		Calves moved to new cow shed (I)	
	Apr		Cows still sensitive to ketosis (I)	Happy to expand social network and gain experience

			(I)
5 (P5)	Mar	Lack of employees and low economic scope (I). Issues with calf mortality (I). Old mattresses in cubicles (F, I). Herd expansion –> old cows retained (I, O). From 3x milking to 2x milking (I, O)	Expects to gain inspiration from conversations and input on management of employees and calf mortality (I)
	Apr	Lack of employees and low economic scope (I). Issues with calf mortality (I). Old mattresses in cubicles (F, I). Herd expansion –> old cows retained (I, O)	
	May	Lack of employees and low economic scope (I). Issues with calf mortality (I). Old mattresses in cubicles (F, I). Herd expansion –> old cows retained (I, O)	Inspired by Herd 6's approach to separating cows with *S. aureus* (F)
	Jun	Lack of employees and low economic scope (I). Acidifying milk for calves, use of active coal, P5 only calf manager – fewer dead calves (I, F). Old mattresses in cubicles (F, I). Herd expansion –> old cows retained (I, O)	Discouraged by systematic treatment of calves with diarrhea (O, I)
	Jul	Lack of employees and low economic scope (I). Old mattresses in cubicles (F, I). Herd expansion –> old cows retained (I, O)	
	Aug	Lack of employees and low economic scope (I). Old mattresses in cubicles (F, I). Herd expansion –> old cows retained (I, O)	
	Sep	Lack of employees and low economic scope (I). Issues with fresh cows (F). Old mattresses in cubicles (F, I). Herd expansion –> old cows retained (I, O). Increased SCC due to changed milking procedure in March – milk yield now back at usual level (I)	Considering performance measurements and weekly meetings with employees (O, I)
	Oct	Lack of employees and low economic scope (I). Old mattresses in cubicles (F, I). Herd expansion –> old cows retained (I, O)	Lack of competent employees and supporting boss perceived as a barrier for change (I, O)
	Nov	Lack of employees and low economic scope (I). Old mattresses in cubicles (F, I)	
	Dec	Lack of employees and low economic scope (I). Old mattresses in cubicles (F, I). Fixing milking equipment + selling old cows –> SCC decreased (I)	
	Jan	Lack of employees and low economic scope (I). Old mattresses in cubicles (F, I)	
	Feb	Lack of employees and low economic scope (I). Old mattresses in cubicles (F, I)	
	Mar	P5 leaves job – bought own farm (I). New mattresses, change of employees (F)	
	Apr		Perceives the SS as time and space for reflection (I). Realizes that no employees are irreplaceable (I). Glad to see that things are also bad at other farms (I)
6 (P6)	Mar	Previous issues with *S. aureus* mastitis, separated in shed –> SCC decreased (I)	Expects input on challenges with mastitis and diarrhea among calves (I)
	Apr	Check of robots –> SCC under control (F); Robots break down –> milk yield decreases (I)	

May	More water added to feed (I) Ventilators in cow shed (I)	Visit from feed advisor –> supports input from SS –> boss convinced (I)	Withdrawn in SS (O). Considers input on pickup routines among first parity cows, lack of staff becomes a limitation (I)
Jun	Materials for correcting cubicles ordered (I)	Many calves born –> increase in milk yield (I)	
Jul			
Aug			
Sep	Initiated correction of cubicles – faced difficulties (I)	Milk yield of first parity cows increased (I)	
Oct	Correction of cubicles (I)		
Nov	Correction of cubicles (I)	Lack of employees (F) Increased milk yield (correction of cubicles and music in stable) (I)	
Dec		Stabilized increase in milk yield (F). Heifers with pneumonia (F). Changing delivery terms for beef calves –> new housing solutions in pairs (F). Heifers with lameness issues –> riffled floors and new mattresses in heifer area (I)	
Jan		Heifer health increased (I, F)	Strong presence in SS (O). Happy with confirmation of plans related to housing of calves and renovation of heifer area (I). Inspired by heat management in Herd 1 (I, O)
Feb		Heifer health increased (I, F). Faster culturing of cows after herd testing (I)	
Mar		Last mattresses in heifer area renewed (I)	
Apr		Change of two oldest robots planned for autumn (I)	Gradual increase in self-confidence, new way of thinking, more experience (I)

[1]As perceived by the source of the statement (interviewee, observer, facilitator, participants).

Changes instigated as part of the Stable School

As illustrated in Table 5, participating herds experienced different types of herd-specific changes. Multiple changes were implemented for some, while no changes were identified for others. Some herds implemented structural changes, while in others, the operations manager expressed some personal development, i.e. an increase in self-confidence and farming experience. Examples of specific change processes, both structural and non-structural, are given below.

Structural changes

For Herd 1, a structural change in claw bath routines was implemented as a result of the first Stable School meeting at the farm. Their previous procedure was for cows to pass through a bath with lime and another with a soap mixture twice a day. Other participants shared their experiences and recommendations of what to change. P3: “Personally, *I would only use the claw bath in the morning – they easily get foot rot from even a small ulcer from entering the claw bath twice a day. We often see that. We only use claw baths once a week. If a lump* [of lime] *sits there, it* *can result in an ulcer. So I would change it to once weekly – just in the morning. Make sure the consistency is thick so that it sticks. Those cases of foot rot you told us about, they might be due to this procedure.*" With this input, P1 agreed that only once a day might be enough, while P6 added: "*I agree that you should only use the claw bath once a day, but I also think you should change your routine; start with the soap mixture because lime forms a crust and I don't think you will have any success with the soap if it washes that crust away. Instead, you are just washing everything away. If you used the soap two days before the lime, you would benefit from all of it.*" As a result, P1 committed to change their claw bath routines to twice weekly, alternating between lime and soap baths. P1 reported at the next Stable School meeting that the new routines had been implemented successfully, using only lime and no soap, and that they had already experienced fewer cases of digital dermatitis and foot rot. They also started to use lime in the cubicles every second day instead of twice weekly. In this case, the practical and easily implementable advice given by the other participants, in combination with a plausible explanation for why their current procedures might not be sufficient, were enough to convince P1 to change practices.

Another structural change instigated by the Stable School occurred in Herd 2; the start of insemination was changed from 40 to 60 days after calving. P2 explained: "[The other participants] *asked if there was any special reason for starting insemination 40 days after calving. There wasn't – it has just always been that way. So we just changed it, without doing any calculations. I remember one of the facilitators told us to be sure to make some calculations before doing it, but I am stubborn and decided to just change it. So we did.*" In this case, the change was easily implementable and did not require much effort from the operations manager. At the final interviews, she mentioned that she did not need to engage other workers at the farm for the change to happen.

For Herd 3, the other participants inspired the herd owner (P3) to improve the ventilation in the old calf shed. P6 commented: "*I don't think the air quality is good in there. I wouldn't want to sleep down there! Personally, I would remove the side of the cowshed – from the roof to the floor on one side – all the way so that they can get some air. Calves need fresh air.*" This was followed by a suggestion from P5 to decrease the occurrence of pneumonia among calves: "*If we start by focusing on things you actually can do: shave their backs when they are moved into a pen with other calves. I don't know what you use to treat pneumonia, but if you use Medicine A*, then you can buy two bales of hay for that price and use that instead. It is cheaper to avoid sick calves in the first place*." As P3 explained, these suggestions required minimal input from him and his co-workers and it made good sense to him. He described the visit and the comments from the other participants as a revelation: "*Participating in the Stable School made us aware of that area. They come and look at everything. That opens your eyes and changes what you used to do*." Therefore, he decided to implement the advice given by P6.

Visiting other farms and seeing how things work was an inspiration for structural changes. P1 explained: "*I was especially inspired by P6. I think it's about two years since he started working with milking robots. It has been a great help with new input and inspiration from him. At the meeting at his place, I saw his plan and how he worked with the robots. They have 10-15 years of experience with milking robots.*" P3 had also been inspired by some of the procedures at Herd 6: "*We talked* *about* [separating cows with *Staphylococcus aureus*] *when we were at his place. They struggled with cows with* S. aureus *some time ago and they tested all the cows. However, they are quite a bit further along in the process than we are. It's also different with milking robots. But we talked about it at that meeting.*" For some, motivation for change was also due to some level of competition, as they were driven by the desire to be better in terms of production and health compared to the others.

Non-structural changes

The participants also spoke about non-structural changes. P1 explained about a change in attitude, in how his perception of treatment had changed during the Stable School as he gained more and more experience in farming: "*We are now faster at identifying and treating cows with mastitis so that they can recover sooner. If you wait too long, you might end up needing to treat her twice. Then you lose the milk for 12 days and that amounts to a lot of money. Now we can diagnose sooner, separate, apply peppermint lotion and look at her: how is she? What does the udder look like? Is it bloody, warm, filled with mastitis? Can we help her? We use the California Mastitis Test on our cows and if we are of the opinion that we cannot help her with treatment, we do not initiate treatment and waste a lot of medicine.*" Furthermore, the focus on which type of antimicrobial to use has increased, as explained by P1: "*I have more experience with using medicine now. When I need to treat a cow, I think: when? And why? Instead of just mixing types of medicine – if it has an infected leg, you choose that type of medicine, if it has a retained placenta, another type of medicine is required.*" In addition, Herd 1 implemented several alternatives to antimicrobials such as oral feed supplements.

The exchange of attitudes was a natural part of the conversations during the meetings. Procedures for handling acute mastitis caused by *Escherichia coli* where the infected teat never fully recovered were discussed at meeting 10. In relation to a mastitis outbreak in Herd 3, P3 explained their procedure: "*I believe we managed to cure 7 out of 10 cows. At our veterinary visit yesterday, however, eight teats were amputated. This is the only solution when inflammation is on the inside.*" This caused discussions among the participants as P1 and P6 believed that teat amputation is a bad solution as it spreads the infectious material and agents in the environment, increasing the risk of infection for other cows. Furthermore, they believed that the teat could never be milked and would spontaneously dry off. The facilitator added that the risk of personnel milking the dried off teat by accident was worth considering, leading P3 to agree that teat amputation was a precaution. P6 commented: "*that should not happen though*", while P3 added the concluding remark: "*but we are working with people…*" In this example, P3 did not change his attitude in that moment, but he was confronted with other perceptions, which made him reflect on his own procedures.

During another meeting, P6 requested input on future management when calves were to be housed in pairs, and clarified their current calf management routines. The other participants believed that the amount of milk given was too low, which P6 then justified: "*People say that. However, if they get more milk* [more than 2.5 liters at a time] *they get diarrhea. We have tried it – even with a gradual increase.*" P3 asked what kind of milk was given, and P6 clarified that milk from cows undergoing treatment or with a high SCC was used, which prompted P3 to say: "*Don't you think it is a matter of the milk used then, rather than the amount? A calf shouldn't get diarrhea* *from milk.*" The discussion finished with a closing remark from P6: "*As long as our buyer expresses his satisfaction with the quality of the calves – he says we deliver the nicest bull calves… And that must also be true for our heifer calves… As long as he continues saying so, we won't change anything.*" In this case, P6 was less inclined to adapt to the attitudes of the other participants, as he deemed the current situation acceptable.

These examples illustrate how the Stable School offered the opportunity to share experiences, attitudes and practices in a safe and confidential environment, as emphasized by P2 and P6. [P2] "*Very honest things were said. It's nice to not only hear about all the perfect things* […]*, the group was so small and I didn't know any of the participants beforehand, so I wouldn't expect any of them to go and share what was said within this confidential group.*" [P6] "*You don't feel ridiculed in any way. It's one thing to feel stupid before you enter the meeting, but if you also feel stupid when you open your mouth during the meeting, then you wouldn't contribute at all.*"

The environment also allowed participants to share procedures they were not proud of. P5, for example, used Halocur (halofuginone lactate) for the first 7 days of the calves' life: "*I'm tired of this systematic use of Halocur, however, it does not appear as if we can do without it*." This attitude did not necessarily change during the meeting, but being able to share without feeling judged or forced to adjust to others' opinions sometimes led to a change in management and attitudes, as seen in Table 5.

P5 reflected on his gradual change in attitude during the Stable School. At the meeting at his farm, some participants suggested that he dismissed the employees with whom he was dissatisfied. This was not perceived as a good solution by P5 at the time. However, at the final interview, he reflected: "*I remember that many of the other participants said that we should dismiss the employees that weren't performing well enough. The problem is that you cannot take care of 500 cows on your own. So… the fact that the employees terminated their employment themselves is another situation… But on reflection, you need to remember that nothing is that important that it can't be replaced.*"

Participants mentioned that they experienced personal development throughout the Stable School period in terms of farming experience and self-confidence. They became increasingly confident in their own decisions and attitudes in farm management throughout the period. This also resulted in an increased influence at their respective farms, as exemplified by P6: "*I have improved – when my boss* and I discuss something… Previously, it was very much my boss that made all the decisions, but now I have gained more courage to go to him and tell him my honest opinion about things – also when I think the decision is a bad idea.*" Some participants mentioned a development within the group dynamic. At the beginning, they were taciturn and withdrawn at the meetings. This could be due to a perceived lack of experience and few ideas to contribute, a language barrier (P1 was not a native Danish speaker), or just a reluctance to speak up in larger groups. P1 described this: "*The first meeting was not so good. I had to think a lot about what was being said, and I didn't understand much. However, since then, I have started talking more and also contributed with suggestions and advice.*" As the group became more familiar with each other and the facilitator steered the conversations and ensured contributions from all participants, everyone took on a more equal role within the group.

Farm-related barriers to change

Few structural changes were implemented in Herd 5. P5 perceived this as a result of the quality of available employees and his own position as operations manager without the authorization to dismiss employees or the opportunity to offer economic bonuses as motivation, as well as lacking support from his boss. P5: "*The owners of Herd 3* had some of the same issues with employees as I did, but they were fortunate because they also paid their salaries. That gave them the power to manage their employees, a power that I didn't have.* [...] *Furthermore, the boss and I had different ideas about what was needed. We had very different priorities* [...] *It has been difficult. I don't know if it is because I'm not the farm owner, but there has been an attitude among some of the employees – a reluctance to change. I tried to explain many times, but they had just decided that it wouldn't work even before trying. I have also asked employees why they milk the way they do, and when I showed them a different way, they just replied: when we are milking, we decide how to do it. Changing things then becomes very hard.*"

Some of the participants experienced stressful times at their respective farms, which meant that they could not participate in some of the meetings. This stress sometimes resulted from having too few employees, as already exemplified by P5, making it difficult to implement the changes suggested at the Stable School meetings. This was also described by P2: "*At the time we started* [the Stable School]*, I had this hope that I could bring back something we could discuss at home – with the employees, so we could start to reflect on what we do and why we do it that way. My wish was to integrate some of our employees to a greater degree – make them more interested in farming. However, I gave up on that wish entirely... I have talked to my boss* about some of the things I saw, but none of the employees were engaged. Of course, the staff today is completely different from when we started* [...] *It has been difficult to find the time and energy to motivate people, for example with those claw baths, without me having to stand there holding their hand. It has been difficult.*" For others, the stressful time was a result of having a high level of disease occurrence and still being in the phase of finding their own "ground management level" where things run smoothly. This meant that they were less open to the other participants' suggestions for changes, as they had already tried many things at the farm and they were in a position where they wanted to try things at their own pace. This was described by P3: "*I thought the input was useful, but it's difficult because many different things are always happening here. We have tried so many different things during our time at this herd, which makes it difficult for the others to come up with suggestions.*" These stressful times seemed to have a negative impact on the benefit farmers gained from participating in the Stable School.

Even though some of the herds experienced few structural or non-structural changes, the participants still expressed positive feelings about being in the Stable School: [P5] "*It's not nice to say, but it has been comforting to look at others farms and think: "thank God I don't need to be here tomorrow!" I am sure some of the others also thought the same when leaving our herd.*" P2 also expressed how seeing other herds in a worse condition brought some comfort: "*Herd 3*, they are not having an easy time. It seems like everything that is suggested out there doesn't work because* *they have already tried everything. Same with Herd 5* and his issues with his employees. Our herd is in a better overall position.*"

Lessons learned: Stable School-related barriers to change

Besides the conditions at different farms, the individual interviews and observations of meetings also revealed barriers to change related to the Stable School procedure. These can be seen as elements that are important to consider when planning and running future Stable Schools.

Group composition and commitment

At some of the meetings (3, 6, 7, 8, see Table 3), only three participants were present due to cancellations shortly before the meeting was held. The many cancellations sometimes had an effect on the commitment and motivation of the group participants, and it changed the facilitators' role at the meetings. This was explained by F1: "[...] *I'm not very good at keeping up with the formal framework. I actually heard P2 saying that we, the facilitators, had played too big a role in that meeting and that she looked forward to the second visit where hopefully more farmers would attend.*" Further reflecting on that, F1 elaborated: "*I think it's important* [that farmers and not veterinarians give advice]*. It makes you reflect on how you can do things differently. Much more than in the case where advisors give their opinion. Those opinions are "too easy"; the advisors haven't experienced those things themselves – not in the same way as farmers have.*" With too few participants, the amount of advice given was also limited, as described by P3: "*It's not enough when there are only two people there. It's much better when around four people visit. Then there is a higher chance that someone has actually experienced the issue before.*"

However, the smaller group also had a positive influence. Some of the participants experienced a more relaxed atmosphere where discussions were steered less strictly, which they found more comfortable. As described by P2, the smaller group made the meeting more chaotic, but also made it easier for everyone to contribute: "*It is calmer when fewer people are present. It's easier to hear each other when the group is this size and no one can hide away.*" P6 agreed with this attitude: "*It is almost as though this group size is a better fit [...] It's easier to contribute when you don't need to compete with three others who also want to say something.*"

The participants reflected on the composition of the group in relation to personality, age and experience, i.e. whether a homogeneous or heterogeneous group was preferred. P6 elaborated: "*I think it was good to have so many different personalities. If everyone had been like P5* [outgoing and communicative]*, I would have felt left out. I think it's good that we were a heterogeneous group.*" P2 reflected on the impact of having the same level of farming experience within the group: "*If the age varies 20-30 years* [within the group]*, you feel left out if you're in your early twenties and don't have a lot of experience. It might also be that the older ones think that this is a kindergarten in terms of experience.*" In contrast, P6 could also see some benefits of having farm owners with responsibility, in-depth knowledge of prices and numbers and years of experience in the group. They could offer some different insights into farm management and give recommendations to the operations managers in the group, for example how to persuade their bosses to make certain changes. Some of the participants highlighted that the homogeneity within the group in relation to experience and age had created a sense of trust, openness and a willingness to share within the group. P5 mentioned how this tone would have changed if older and more experienced farmers had been present: "*Personally, I don't use the same wording if I talk to someone 10 or 20 years older than myself.* […] *I think it's easier to make recommendations about how to do things differently when you are the same age.*" The participants and the facilitator had no uniform answer about how a Stable School group should be established, but agreed that a trusting and committed atmosphere should be sought and that participants should have enough farming experience to contribute to an adequate outcome from the meetings.

Facilitation and facilitator tasks

The participants had different views about the necessary degree of steering by the facilitator(s). P5 in particular advocated for less strict steering: "*It's important that two people can speak freely and that others listen – they can also learn a lot from it. You can learn many things from those conversational tangents.*" Other participants had contrasting views and requested a stricter steering of the group to avoid dominance by some participants. Furthermore, as mentioned by P6, the steered discussions gave him a sense of progression and minimized the feeling of wasting time. It was important to him that he returned to work to on time, which he felt was more likely at meetings where the facilitators took responsibility for steering the conversations and keeping to the agenda. Furthermore, some of the participants emphasized the importance of the facilitator's role of maintaining the structure of the meetings, i.e. by sending out agendas before the meeting and minutes after the meeting, as they used these to prepare themselves for the meeting in order to offer their best possible input to the host. However, not all of the participants prioritized following the structure of the meetings. They felt that they would have no time to look at the agenda before the meeting, but acknowledged that the needs of everyone in the group should be met: [P3] "*It needs to be a structure that works for everyone. Also in terms of the discussion steering; not everyone is good at sticking to the structure, which leads to others not contributing as much. That's why the round-principle is good – everyone is heard.*" It therefore seems important to aim for balanced facilitation that accommodates the needs of all participants in the best way possible and ensures equal contribution.

Veterinary practice as facilitators

Through meeting observations, the first author identified an imbalance in the relationship between the participants and the facilitators; some of the participants already knew the facilitators because they were the herd veterinarians at the farm. This was observed in the interaction between these participants and the facilitator(s) – at times, they expected scientific input from the facilitator(s), as they were accustomed to that in their advisory relationship. Another aspect was that these farms had regular visits by the facilitators in between the Stable School meetings, implying that they were confronted about the changes they had committed to implement at the meetings more regularly and outside of the Stable School. Furthermore, Facilitator 1 mentioned the benefit of knowing some of the operations managers beforehand in relation to steering and facilitating the group members. None of the interviewed participants or facilitators mentioned this imbalance, but the general advantage of having facilitators with a thorough knowledge of and regular visits at the participating farms might be important to consider when planning future Stable Schools. Furthermore, F2 was of the opinion that having veterinarians as facilitators (as opposed to other types of dairy advisors) was beneficial because they had the skills to correct any scientifically incorrect (in relation to health promotion) or illegal advice given by the participating farmers.

Common goal setting

All of the participants agreed that the common goal of the Stable School, "improved health – fewer antimicrobials", had been addressed to a limited extent. F2 mentioned that "promoting production" had developed as the primary focus. One of the participants was of the opinion that working toward a common goal was important for the participants' motivation for change. He suggested that specific goals for treatment or production levels could have been set for the participants, and that results could have been shared at each meeting. In his opinion, this would have increased the coherence in the group and supported a more focused effort on the participating farms. F1 shared the opinion that going through specific numbers of e.g. herd yield and treatment levels at each meeting might have been beneficial. However, he was also of the opinion that the common goal could be too narrow; that it was important for participants to choose the issues relevant to their farm, otherwise it could impede their motivation for change. Furthermore, he felt that the interruption to the Stable School process due to e.g. COVID-19 and farm-related barriers hindered the coherence and focused effort within the group. F2 mentioned another aspect: how the group had a very uniform approach to AMU and that having participants with different attitudes toward AMU (e.g. organic producers) might have resulted in a bigger change in attitude and practices. As illustrated, external circumstances might have a considerable effect on the participants' outcomes, but addressing the common goal frequently and categorically by going through specific farm numbers and having a heterogeneous group in relation to attitudes might assist in enhancing the outcome.

Naming and expectations

At the beginning of the Stable School, few participants were familiar with or aware of the concept of the Stable School, i.e. mutual experience sharing instead of input from experts. As F1 pointed out in the final interview, the name "Stable School" might be misleading. The word "School" might create expectations among participants that they should learn something, i.e. receive lessons. This was also illustrated by the fact that some of the participants requested more scientific input from F1. Even though the concept was introduced thoroughly at the introduction meeting, a greater emphasis could have been put on explaining the idea behind the concept for better alignment of expectations between the participants and the facilitators. When planning future Stable Schools, the name might need to be reconsidered to better illustrate the content and purpose of the Stable School concept and ensure recruitment of participants interested in and motivated by such processes.

Monitoring graphs: development in treatment risk and milk yield during the Stable School

The previous sections presented an in-depth knowledge of some of the change processes and barriers to change on the different farms. This section presents farm-specific developments in weekly overall treatment risk and daily deviation from the prior milk yield during the Stable School. These graphs were considered retrospectively, which allowed us to add qualitative observations on farm-specific changes from Table 5 with potential relevance to the development in milk yield or treatment risk as horizontal lines on the graphs. Furthermore, the parameter estimates for the models are presented in Table 6 in the Appendix. Brief guidance on how to read and interpret the graphs will be given for the first herd.

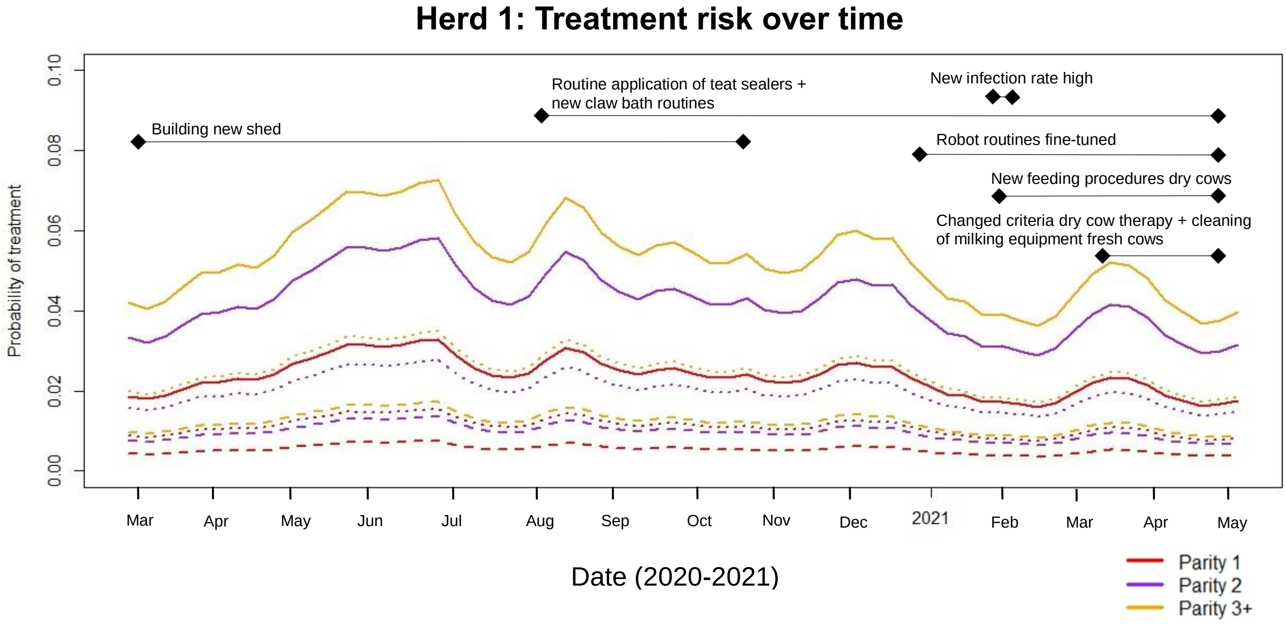

Figure 1. Week-by-week monitoring graph showing herd-level probability of treatment distributed by parity and days in milk (DIM) over time in Herd 1. Relevant information about changes in Herd 1 were added from Table 5. The probability of treatment for cows 0-60 DIM is shown as solid lines, 61-280 DIM as stippled lines, and more than 281 DIM as dotted lines. This graph has also been used in the paper by Skjølstrup et al. (2021b), but without the horizontal text lines.

The x-axis of the treatment risk monitoring graphs (e.g. Figure 1) shows the time since the start of the Stable School. The y-axis shows the probability of treatment in a specific week. For example, in the first week of March 2020, there was a 4% probability of treatment among cows in early lactation in parity 3+. The treatment risk is assumed to be constant across the different parities and stages of lactation, and fluctuations in the graph are therefore due to the random herd-level week effect that is autocorrelated. Furthermore, no interaction between parity and stage of lactation was assumed (this was tested for Herd 1). Therefore, the lines representing the different parities and stages of lactation will never cross, and treatment risk should only be evaluated at herd level. Fluctuations in the graph will represent periods with changes in management or other changes with an influence on the herd-level treatment risk, so qualitative data on identified ongoing changes in the herd were added to the graph. For example, shed building from March 2020 to November 2020 could explain the increase in herd-level treatment risk during that period. Fluctuations in treatment risk will not be due to a larger number of animals present in the herd that day, nor due to a larger number of multiparous cows or cows in a higher-risk stage of lactation, as the model accounted for these effects.

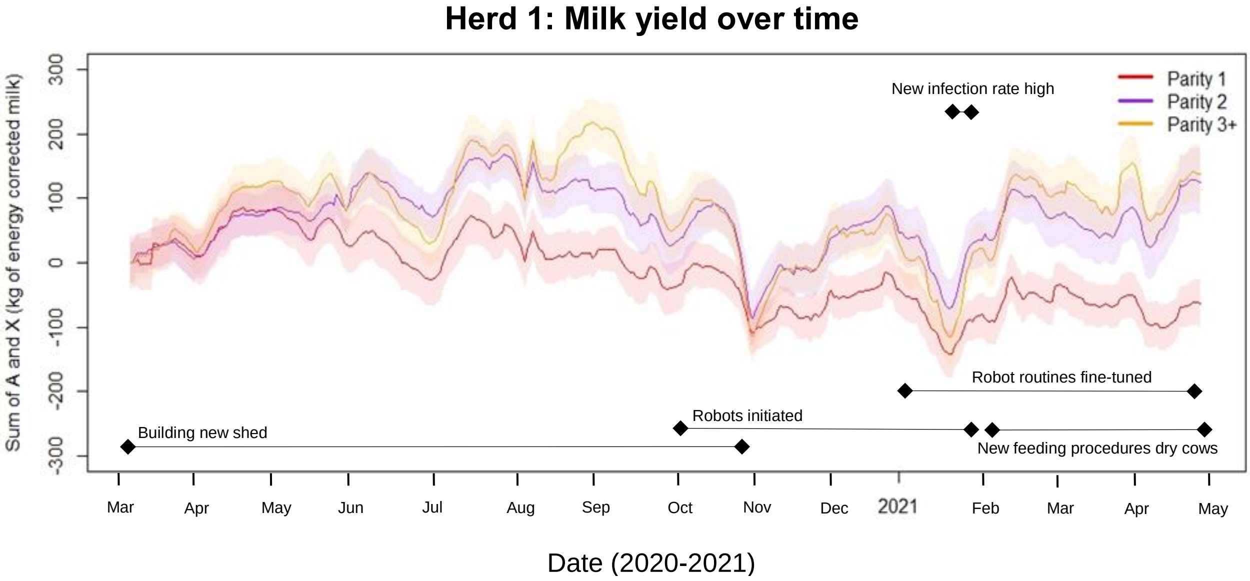

Figure 2. Day-to-day monitoring graph showing the sum and 95% confidence intervals of the estimated parameters A and X per parity over time in Herd 1. The sum shows the daily deviation in kg of energy corrected milk from the herd's average lactation curve for each parity, taking into account environmental effects and stage of lactation. Relevant information on changes in Herd 1 were added from Table 5. This graph has also been used in the paper by Skjølstrup et al. (2021b), but without the horizontal text lines.

The x-axis of the milk yield monitoring graphs (e.g. Figure 2) shows the period since the start of the Stable School. The y-axis shows the daily deviation in milk yield (in kg ECM) for the different parity groups according to the modelled average lactation curve estimated at the beginning of the monitoring period (March 2020). The daily deviation in milk yield was calculated as a sum of the production potential of each cow (compared to the herd average), A, which is constant over an entire lactation period for each cow, and the local production effect, X, which evolves daily and assumes within-cow autocorrelation, i.e. a high-yielding cow is also assumed to have a high yield the following day. Daily estimation of the sum (A and X) also provides estimates of the variation in these estimates, plotted as 95% confidence intervals for each parity, thus describing the summed variation from the herd's average lactation curve. As the graphs are smoothened, data from the whole period are used at every time step. For that reason, analysis and interpretation of results should be done retrospectively. If the herd-level milk yield level remains the same during the Stable School period, the sum for the different parities would always be zero (some cows will be above average, others below) and all graphs would remain at that level. However, if the herd-level milk yield improves, the sum will increase, and this increase will not be due to an increased number of cows in the herd on that day, nor due to a greater number of higher parity cows or a greater number of cows in early lactation (with a generally higher yield), as the model accounts for these effects. Instead, reasons for increased herd-level milk yield can be explained by management changes relevant to milk yield found in the qualitative data. Results from time points that are further from March 2020, when the average herd lactation curve was estimated, should be interpreted more cautiously, as the average herd lactation curve will most likely have changed over time.

The following graphs for the other herds should be read and interpreted in a similar manner. Discussions of the individual herds will be presented in the following section.

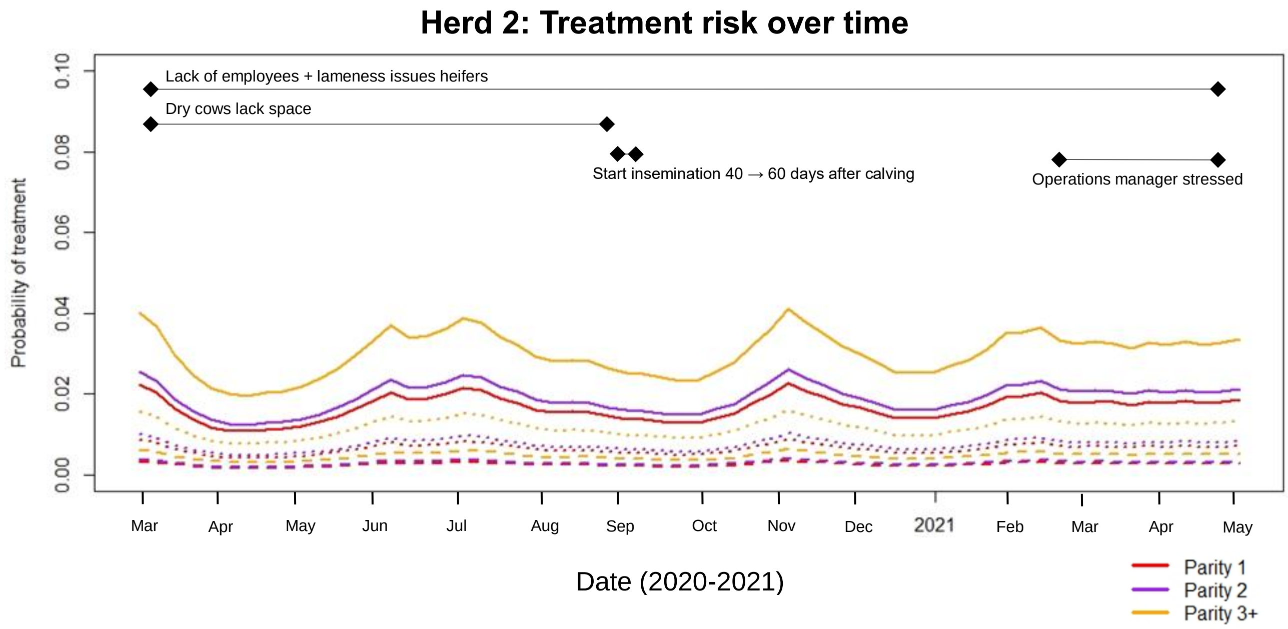

Figure 3. Week-by-week monitoring graph showing herd-level probability of treatment distributed by parity and days in milk (DIM) over time in Herd 2. Relevant information about changes in Herd 2 were added from Table 5. The probability of treatment for cows 0-60 DIM is shown as solid lines, 61-280 DIM as stippled lines, and more than 281 DIM as dotted lines.

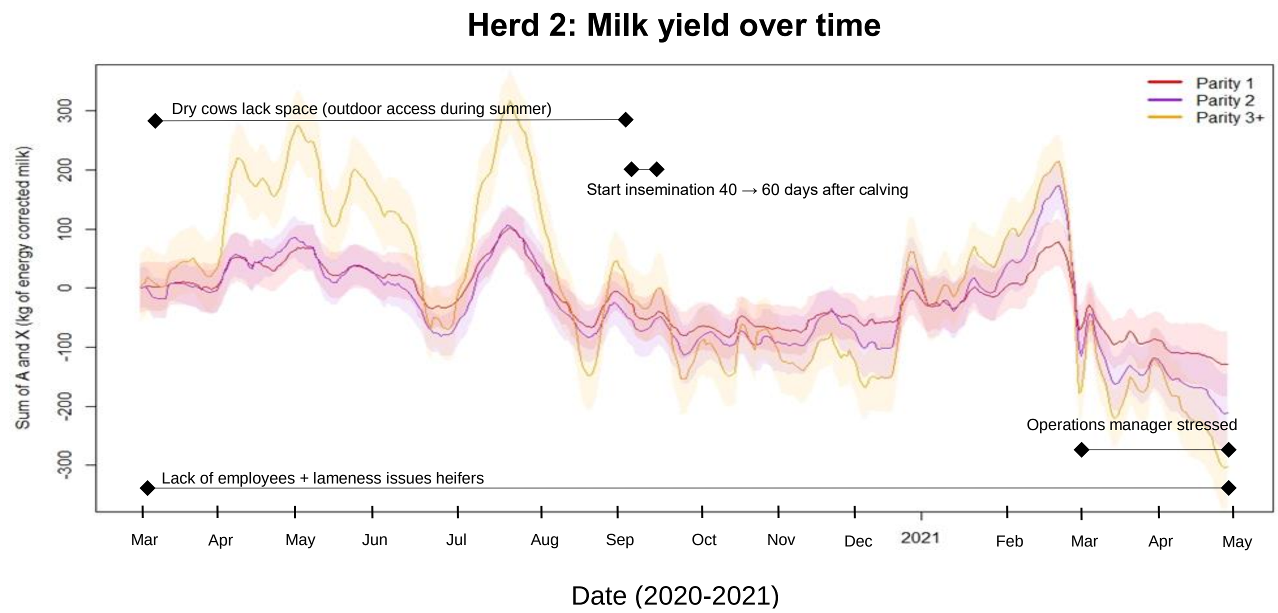

Figure 4. Day-to-day monitoring graph showing the sum and 95% confidence intervals of the estimated parameters A and X per parity over time in Herd 2. The sum shows the daily deviation in kg of energy corrected milk from the herd's average lactation curve for each parity, taking into account environmental effects and stage of lactation. Relevant information on changes in Herd 2 were added from Table 5.

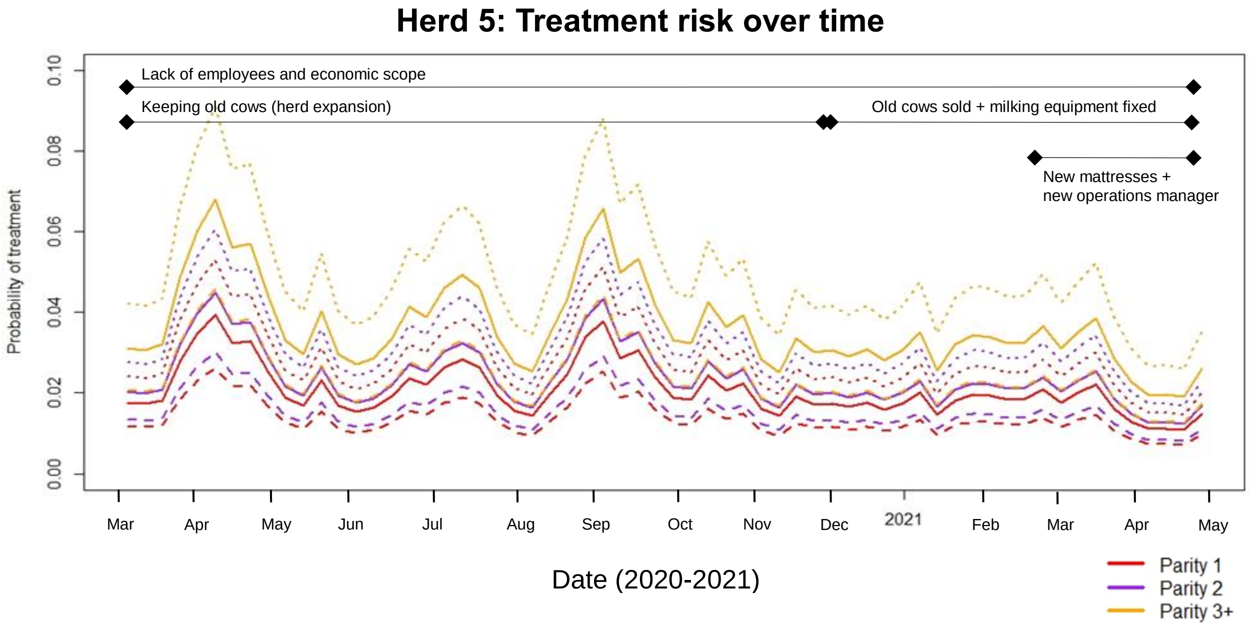

Figure 5. Week-by-week monitoring graph showing herd-level probability of treatment distributed by parity and days in milk (DIM) over time in Herd 5. Relevant information about changes in Herd 5 were added from Table 5. The probability of treatment for cows 0-60 DIM is shown as solid lines, 61-280 DIM as stippled lines, and more than 281 DIM as dotted lines.

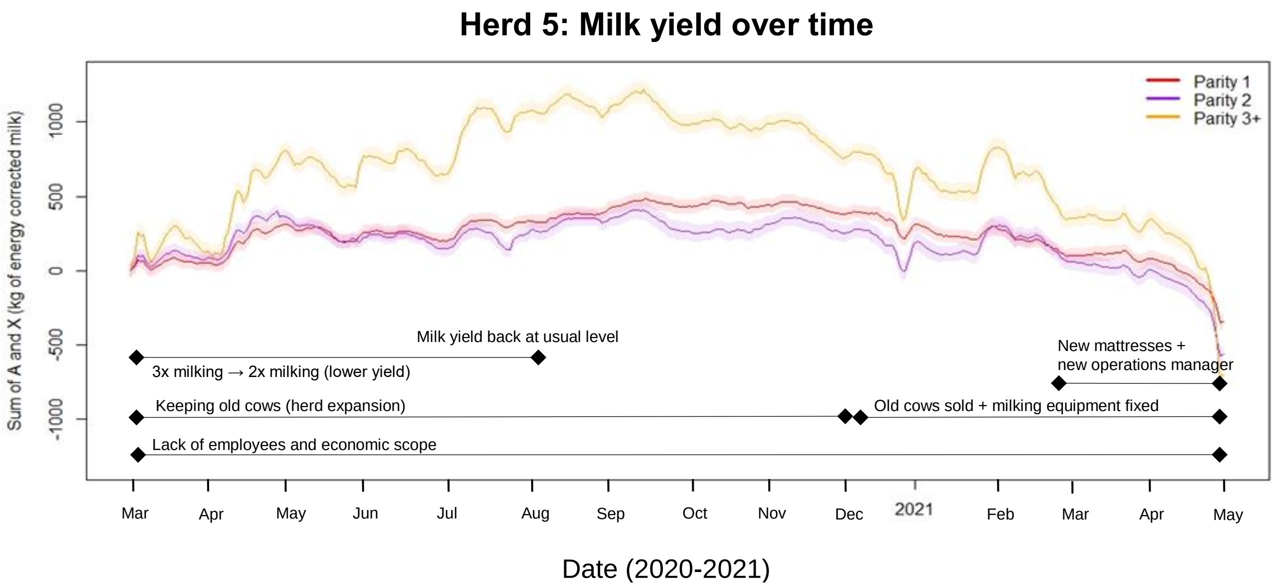

Figure 6. Day-to-day monitoring graph showing the sum and 95% confidence intervals of the estimated parameters A and X per parity over time in Herd 5. The sum shows the daily deviation in kg of energy corrected milk from the herd's average lactation curve for each parity, taking into account environmental effects and stage of lactation. Relevant information about changes in Herd 5 were added from Table 5.

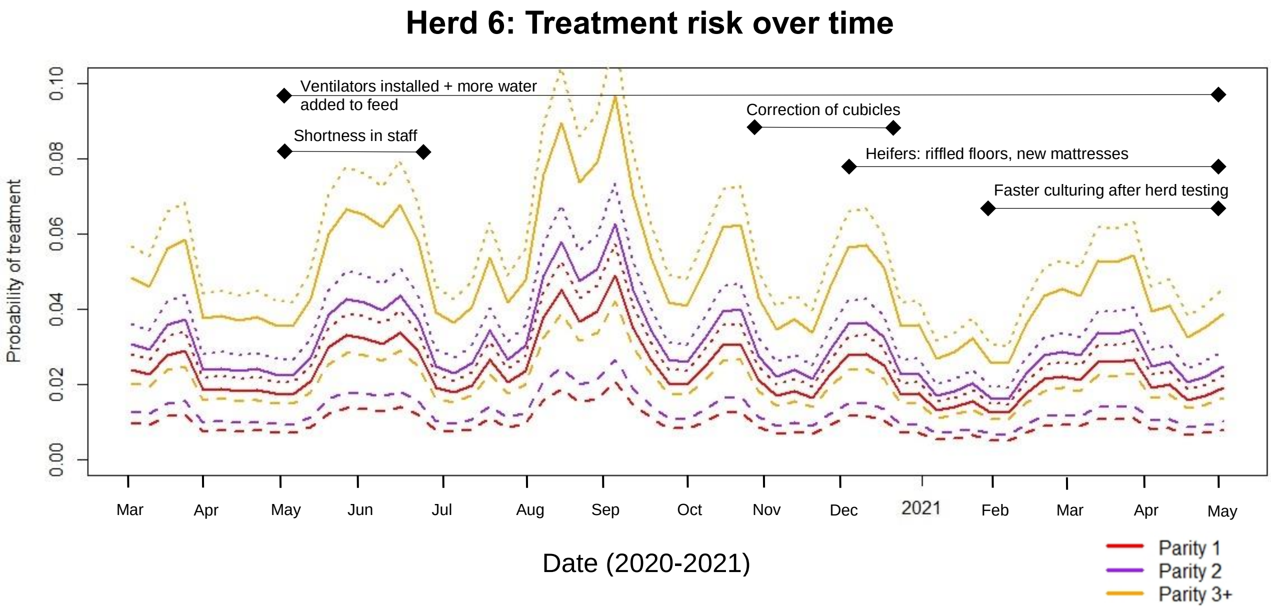

Figure 7. Week-by-week monitoring graph showing herd-level probability of treatment distributed by parity and days in milk (DIM) over time in Herd 6. Relevant information about changes in Herd 6 were added from Table 5. The probability of treatment for cows 0-60 DIM is shown as solid lines, 61-280 DIM as stippled lines, and more than 281 DIM as dotted lines. This graph has also been used in the paper by Skjølstrup et al. (2021b), but without the horizontal text lines.

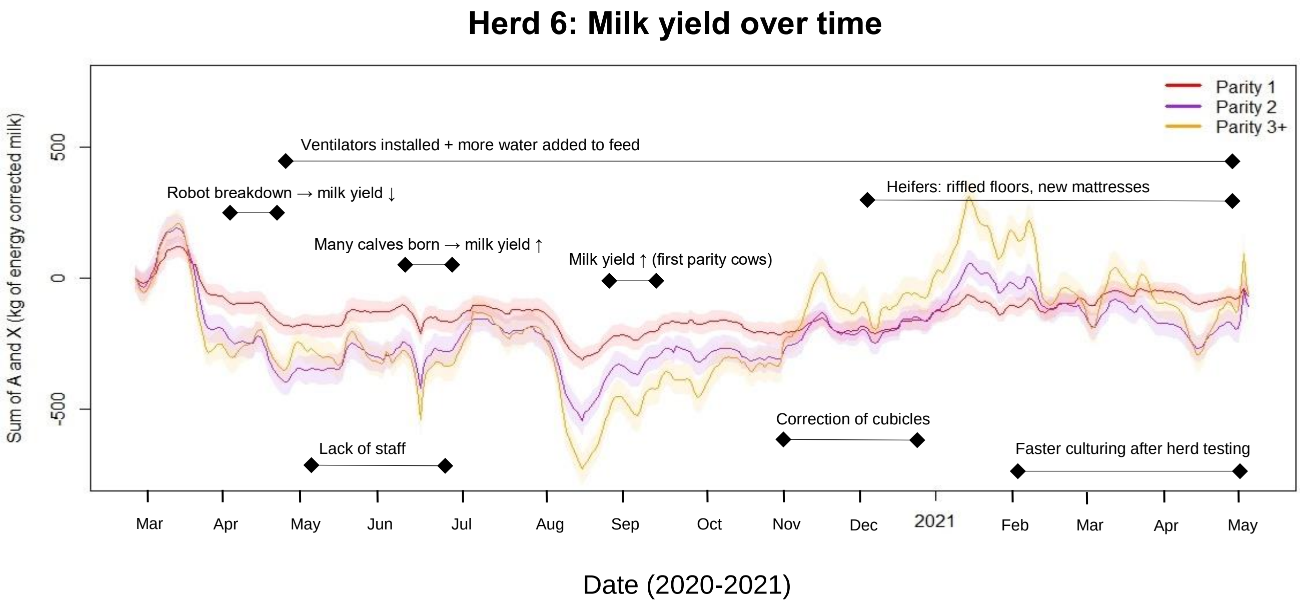

Figure 8. Day-to-day monitoring graph showing the sum and 95% confidence intervals of the estimated parameters A and X per parity over time in Herd 6. The sum shows the daily deviation in kg of energy corrected milk from the herd's average lactation curve for each parity, taking into account environmental effects and stage of lactation. Relevant information about changes in Herd 6 were added from Table 5. This graph has also been used in the paper by Skjølstrup et al. (2021b), but without the horizontal text lines.

Triangulation: combining monitoring graphs and qualitative observations

A mixed methods approach with retroductive data analysis of the qualitative data and SSMs was used to identify change processes at participating farms. In this section, the two types of data (the monitoring graphs in section 3.2 and the implemented changes in Table 5) were combined at the interpretation stage, using triangulation to improve the reliability of the identified changes for each herd separately.

Herd 1 – engaged participation during eventful times

For Herd 1, many structural and non-structural changes were initiated as a result of the Stable School. In terms of structural changes, they were inspired by Herd 2 to start applying teat sealers at dry off, and they changed claw health routines, as well as daily routines related to the newly installed milking robots. As for non-structural changes, P1 became increasingly confident in contributing to the meetings due to a perceived increase in farming experience during the period. At the final interviews, he was very pleased by what he had gained from being part of the Stable School.

Looking at the monitoring graphs for treatment risk, the probability of treatment appears to have started and ended at approximately the same level during the Stable School, with some fluctuations in between. The probability of treatment increased in the intermediate period, e.g. from 4% to 6% probability of treatment among cows in parity 3+ and at the beginning of lactation, 3.5% to 5% among second parity cows, and 2% to 3% among first parity cows. Late lactation saw the second highest probability of treatment, while the lowest probability of treatment was in mid lactation. This applied to all parities since no interaction between parity and stage of lactation was found. This increase in the probability of treatment during the intermediate period could be explained by the fact that a shed extension was built at the same time, leading to stress and a higher chance of illness among the cows. Therefore, participating in the Stable School seems to have had a limited effect on treatment risk, however, when things stabilize following the installation of milking robots and shed-building, a decrease in treatment risk that matched the perception of P1, who believed that they had decreased their treatment rate during the period, might be seen.

The herd-level milk yield also fluctuated over the period compared to the average herd-level milk yield. However, cows in parity 2 and 3+ generally performed better than the herd average for these parities during this period (except for November and February), sometimes with 200 kg ECM more than the average yield. In contrast, cows in parity 1 performed worse than the herd average for parity 1 cows, especially from November onward. Unlike treatment risk, the cows' milk yield did not seem to have been influenced by the shed building, as the milk yield increased or remained stable during that period. Therefore, the qualitative data collection might not have captured some changes at the farm. When the milking robots were installed during October 2020, the milk yield for all parities fell below the herd average. Fine-tuning of robot routines together with changed feeding procedures for dry cows might have resulted in the subsequent increase in milk yield, particularly among older cows. First parity cows seemed to react most to the initiation of milking robots.

Overall, concurrent changes at the farm, i.e. the introduction of milking robots, might have masked the immediate outcome of Stable School participation (or Stable School participation might have smoothened the implementation of milking robots). However, P1's impression of the participation was entirely positive, implying that the qualitative and quantitative results in this case could be divergent (Östlund et al., 2011), i.e. numbers and graphs are not the only indicators of how this farm progressed and responded to changes. Determining which of the data were "true" (P1's perception that the treatment risk decreased or the monitoring graphs showing that it increased) was not the purpose of this triangulation. Instead, these discrepancies raised awareness about the complexity of evaluating farm-specific changes, thereby underlining the need to evaluate Stable School participation from a holistic perspective.

Herd 2 – a well-run herd experiencing a busy period when participation offered time for reflection

Fewer changes were initiated in Herd 2 due to or during the Stable School, but they did change the insemination start time and purchased claw baths. As previously described, Herd 2 lacked employees throughout the whole period, which put pressure on the operations manager, P2, resulting in little surplus energy for instigating changes. Furthermore, P2's motivation for participation in the Stable School generally varied.

The treatment risk monitoring graph shows a relatively stable (differences in probability of treatment of 1-2% over time) level of 1-4% probability of treatment throughout the period, depending on parity and stage of lactation. In contrast, the herd-level milk yield, especially for parity 3+ cows, fluctuated compared to the average herd yield. During the summer months, parity 3+ cows seemed to perform better than average (up to 300 kg ECM more), potentially due to outdoor access during the dry period. The many fluctuations could be due to the changing staff and lack of employees, which makes consistent milking routines difficult. At the end of the Stable School period, a drastic decrease in milk yield was seen (-100-300 kg ECM less), which can potentially be explained by P2 having to leave her job for a short period due to stress. Any other explanations for these fluctuating milk levels may not have been captured by the qualitative data. The triangulation of this herd indicates a relatively well-run herd with a low treatment level participating in a Stable School during a stressful time, which minimized the outcome seen from a production perspective, but treatment levels still did not increase drastically. Furthermore, P2 expressed how valuable the meetings were to her in the sense that they provided space and time for reflection.

Herd 3 – varying herd health and production levels undermined immediate changes

No monitoring graphs were produced for Herd 3 due to issues with data quality and change of owners, which is why evaluation of changes during the Stable School was limited to the qualitative data, and triangulation was not performed. As already described, the owners had recently taken over the herd and still struggled with herd health and production. Therefore, instigated changes were limited. Furthermore, the changes mainly related to calf health, and the developed monitoring graphs would not have illustrated the evolution in treatment risk over time as they only related to cows. Overall, P3 expressed his satisfaction with participation and what the herd had obtained from a production and health perspective. Furthermore, he believed that he had received various good advice and suggestions for changes that could be tested once the herd stabilized.

Herd 5 – participation with gradual attitude change, busy times and a lack of staff

As for Herd 2, few changes were instigated at Herd 5. This was also due to farm-related barriers such as lack of employees and conflicting interests between the farm owner and the operations manager, P5, which resulted in limited economic scope and motivation to initiate changes.

The monitoring graphs show the probability of treatment fluctuated during the period. For example, between 4% and 9% probability of treatment for parity 3+ cows in late lactation and between 3% and 7% for parity 3+ cows in early lactation. The probability of treatment stabilized at a lower level (maximum 5% probability of treatment across all parities and stages of lactation) at the same time that herd expansion ended and old cows were sold off. The specific number of cows in parity 3+ was adjusted for in the model, but the relative distribution of cows in older parities could vary and explain the fluctuating probability of treatment from March to December (older cows in parity 3+ could imply higher disease and therefore treatment frequency). After December, the milking equipment was fixed, potentially ensuring better udder health and explaining a lower herd-level probability of treatment during the following period.

In relation to herd-level milk yield, there had been a change from milking three times a day to two times a day just before the beginning of the Stable School, which according to P5 had resulted in a lower milk yield until August 2020, when the herd was back to its usual milk yield level. Cows in parity 3+ yielded more than average for the herd throughout the whole period (up to approximately 1,000 kg ECM more). Changing the milking frequency might have benefited older cows most. A period of decreasing milk yield followed from October (still above average herd yield for all parities), which could partly be explained by the fact that older cows, which are typically higher yielding, were sold (the relative distribution in parity 3+ changed). However, other explanations for this decrease not covered by the collected qualitative data are possible. The triangulation illustrated that even though few changes were instigated at Herd 5, P5 appreciated participating in the Stable School as it gave him time for reflection and the opportunity to realize that other farmers struggled with similar issues in relation to employees.

Herd 6 – personal development and changes not always reflected in herd health and production measures

For Herd 6, multiple changes were initiated due to the Stable School. The correction of cubicles in areas of the shed that housed older cows (not primiparous) was an example of a structural change. This was initiated at the very first Stable School meeting when some of the participants noticed that the cows seemed reluctant to use the cubicles. Another example of a structural change was the purchase of ventilators for the cowshed, which according to the operations manager, P6, was inspired by other herd visits. In terms of non-structural changes, P6 expressed a gradual increase in self-confidence and farming experience during the Stable School and therefore contributed more and more advice and input at the meetings.

The monitoring graph for treatment risk showed the probability of treatment fluctuated during the period from 1% to 10% probability of treatment, depending on parity and stage of lactation. A shortage of staff might be one explanation for the increase in treatment risk during the first half of the period, yet other potential explanations may not have been revealed by the collected qualitative data. The installed ventilators even appeared to have resulted in an increased treatment risk, as a positive effect (decrease in treatment risk) would be expected during the summer months, but the graph shows an overall increase in probability of treatment from July to September. However, as already stated, these monitoring graphs do not aim to evaluate the effect of changes directly, but merely hypothesize about potential associations. In the second half of the period, i.e. from around September, the treatment risk seemed to decrease slightly (difference in highest probability of approximately 4% for parity 3+, 2% for parity 2, 1% for parity 1), potentially explained by the cubicle adjustments. Furthermore, faster culturing after the monthly herd testing to identify cases of mastitis might have resulted in an increased treatment risk (of around 2%) in February and onwards.

The development in herd-level milk yield was characterized by a decrease (up to 700 kg ECM lower than the average) for parity 3+ cows during the period, followed by an equal increase. Cows in parity 1 had a relatively stable milk yield, but this was slightly lower than the herd average (maximum 300 kg ECM below). Cows in parity 2 followed a similar pattern as cows in parity 3+, with less marked fluctuations. The initial decrease can partly be explained by the milking robots malfunctioning, but other unknown explanations are possible. Correcting the cubicles might have increased the milk yield among the older cows, but this might not be the only explanation for the increase. Overall, the triangulation of this herd clearly illustrates the complexity involved when evaluating the apparent effect of introducing changes. For example, the installation of ventilators was expected to influence milk yield and treatment risk positively, and P6 had the impression that it did, yet the monitoring graphs indicated it did not. In this case, the qualitative and quantitative data collected offered divergent propositions on the effect of the change. Thorough qualitative data collected via conversations with herd owners and operations managers over time is needed to identify all possible explanations for fluctuations in quantitative data in order to offer the most qualified estimate of the potential effects of changes made.

Potential for Stable Schools to instigate a change in antimicrobial use

A marked decrease in probability of treatment was not seen in any of the participating herds at the end of the Stable School, even though this was part of the overall goal "improved health – fewer antimicrobials". This was in contrast to the findings of Bennedsgaard et al., who reported long-term reductions in AMU in participating herds. They primarily identified a reduction in incidence rate for mastitis treatments compared to other disease groups (2010), and it would therefore be interesting to evaluate the treatment risk for specific disease groups in the participating herds of this study. A delayed decrease in treatment risk might be expected as seen in the study by Bennedsgaard et al. (2010). Furthermore, several of the herds might experience less stressful periods with no staff limitations, resulting in surplus energy for testing some of the suggestions given by other participants. Staff limitations were also identified as one of the primary reasons for not changing colostrum management in a study by Koralesky et al. (2021). Similarly, a lack of staff and stressful periods were given as reasons for not immediately following suggestions given by other farmers in a study on Farmer Action Groups (similar to Stable Schools) by Morgans (2019). Similarly, Morgans reported no statistically significant difference in Animal Daily Dose or total AMU on participating farms from year one to year two of their study period, though most of the farms reduced their use of HPCIAs (2019). There is a difference in study context between this study and the study by Morgans; most Danish farmers do not use HPCIAs, so the "low-hanging fruit", i.e. reducing their usage was not applicable in this study. Ivemeyer et al. reviewed multiple European Stable School-related research and advisory activities and their effectiveness. The activities had different setups and were measured by different outcomes, with various effects on AMU (2015). Some activities, e.g. ANIPLAN, demonstrated a significant decrease in the number of veterinary treatments with concurrent stable (or increased) herd health and production parameters, while others had unchanged treatment incidences (Ivemeyer et al., 2015).

Reasons for the limited decrease in treatment risk can potentially be found in some of the identified Stable School-related barriers to change. As already stated, the participants believed the common goal of this Stable School had been addressed only to a limited extent. In comparison, a common and specific goal to phase out antimicrobials was set by the participating farmers in a previous study on Stable Schools for Danish organic dairy herds (Vaarst et al., 2007). Motivation to fulfill the goal probably increased due to support from the participants' dairy company and a general focus and discussion on AMU reduction among organic producers at that time. Therefore, having a specific common goal supported by society or close business partners and including an economic incentive might be beneficial in achieving a considerable reduction in AMU. Another reason for the limited decrease in treatment risk could be that the primary participants in this study were operations managers as opposed to farm owners. Even though most of participating operations managers had a high degree of influence, responsibility and co-determination at their respective farms, they still needed to communicate with their bosses to initiate some of the more pervasive changes. This obstacle was also highlighted in the study by Ivemeyer et al. (2015).

The limited decrease in treatment risk might also be explained by the fact that the advice and initiated changes from this Stable School focused primarily on promoting production rather than reducing AMU, as highlighted by F2. This finding is in contrast to that of Morgans (2019). Despite encouraging a focus on preventive measures and not only AMU-related herd problems, the third most common recommendation given by participating farmers concerned the type of antimicrobials and dosage regimes used (Morgans, 2019). However, in the study by Morgans, farmers had been encouraged at all visits to discuss their current treatment plan with their herd veterinarian, and all meetings started with a round of what HPCIAs had been used since the last meeting. Furthermore, external knowledge about AMU was mobilized and lessons on antimicrobial stewardship were given at some of the meetings, implying that more emphasis had been placed on addressing AMU compared to this study. Morgans (2019) argued that mobilizing external knowledge was a vital element of a farmer-led approach, and this could be seen as a way to achieve a reduction in AMU in the herds participating in this Stable School. That would imply breaching with the co-constructive approach to implementing knowledge in practice, which the Danish Stable School concept build on, and instead approaching the linear model of dissemination from expert to lay person (Klerkx and Jansen, 2010; Noe et al., 2015). The fact that the information was requested by the farmers in the study by Morgans (2019), however, illustrates that the Stable School (or Farmer Action Group) concept has the ability to raise doubt among farmers in terms of their current practices and knowledge, making them open to new information and potential change.

The interviewed participants of this study mentioned that the sometimes insufficient steering of discussions and maintenance of meeting structure by the facilitator diminished their motivation for participation. This could potentially have limited the outcome of the meetings, subsequently leading to fewer changes being initiated, i.e. in relation to AMU. This hypothesis was supported by the fact that the farmers in the study by Morgans highlighted skillful facilitation as a way to encourage participation and improve general outcomes from participation (2019). Therefore, having a more rigid facilitation structure for the Stable School could potentially be crucial for achieving changes in AMU on participating farms.

Even though the outcome of Stable School participation in relation to reducing AMU (and structural changes in general) seemed limited, the triangulation of the quantitative and qualitative data illustrated that other important non-structural changes had been initiated at all of the participating herds. This included an experienced increase in self-confidence and trust in the participants' own farming abilities; this empowerment was also described by some of the farmers in the study by Morgans (2019). Furthermore, as emphasized by the participants of this study, a mutual trust and openness was experienced within the group. This encouraged them to share both positive and negative experiences, thereby enhancing their chances of changing perceptions and practices. This was also described in the study by Morgans (2019). In general, the Stable School concept provides psychological safety, enhancing participants' ability to change and learn (Vaarst et al., 2007; Edmondson and Lei, 2014). It is important to recognize that non-structural changes are also worthy outcomes of participation in a Stable School, and that changes are complex and dynamic, i.e. Stable School participation might have instigated change processes not yet visible in the quantitative data. The same conclusions might not have been identified had the qualitative and quantitative data been analyzed separately. Furthermore, when evaluating the outcome of participation in a Stable School in relation to AMU, the starting level of treatment is important. Sometimes, remaining at the same level might be the goal for a herd participating in a Stable School, i.e. Herd 2 had a generally low level of treatment and therefore had no immediate need to reduce their AMU further. Instead, the goal could be to maintain the status quo. Finally, it is important to remember that Stable Schools are not suitable for everyone; not all farmers will thrive in the structural framework of steered discussions and mutual learning. They may prefer to change their practices and perceptions on other grounds, i.e. through scientific input from their advisor.

It is not possible to know what changes would have been initiated at these herds if they had not participated in the Stable School, but based on the qualitative data, i.e. interviews with participants, we are certain that some of the changes were directly related to Stable School participation. In relation to the quantitative data, i.e. measured changes in milk yield and treatment risk, the aim of this study was not to claim any direct causality between participation in Stable Schools and measured changes. Instead, we aimed to report comprehensively on the changes that occurred during the period from a qualitative and quantitative perspective, in order to describe how participation in a Stable School influenced change processes and motivation among participants. The participants' personal experiences and developments were in focus, and a control group (farmers not participating in a Stable School) was therefore not necessary. A control group (and a larger sample size, e.g. more farmers and more Stable Schools, rather than this single case study) could have been interesting if the purpose was to establish causality between participation in a Stable School and changes in e.g. AMU. It is important to remember that the results of this study are non-generalizable as they are dependent on situation and context. Despite that, we argue that the results can inform and guide future planning, and that Stable Schools with this farmer-led approach comprise an alternative to classical veterinary advisory services.

In future studies, the monitoring graphs from the SSMs should be available to participants while the Stable School is ongoing in order to assess and utilize the motivational effects of seeing their own results. This would also increase the effect of combining qualitative and quantitative monitoring; questions could be asked at the time when fluctuations are seen in the graphs, and potential reasons for these could be found. Furthermore, the models should include youngstock for a holistic picture of the AMU at the farm, as well as measuring more specific outcomes such as mastitis treatment risk instead of overall treatment risk to further evaluate where specific changes can be seen.

Conclusion

Stable School is a facilitated farmer-to-farmer experience-sharing alternative to the top-down flow of knowledge seen in classical veterinary advisory services. Participation in a Stable School provided a reflective and safe platform for sharing experiences and initiating change pathways in relation to AMU and other farm-specific issues. A limited decrease in treatment risk was seen in the participating herds, however, arranging the structural framework based on balanced facilitation, common goal-setting and particular focus on AMU at future Stable School meetings could optimize the outcome in relation to AMU reduction. The mixed methods approach to evaluating changes demonstrated how changes can be measured and perceived differently and illustrates the importance of collecting both qualitative and quantitative data in complex advisory situations to draw nuanced conclusions about observed changes. This case study illustrates how SSMs can be useful as a retrospective monitoring tool. Future studies should investigate the potential for using SSMs in present time combined with qualitative data in a mixed methods approach as a motivational tool for farmers.

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Data availability statement

The R code to develop the SSMs can be forwarded by request to nannaks@sund.ku.dk. The interviews with the farmers and facilitators are confidential data and require further approval to be shared.

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Appendix

Table 6. Estimated initial variables and variance components based on historical data.

Treatment risk – parameter:	**Symbol**	**Herd 1**	**Herd 2**	**Herd 5**	**Herd 6**
Intercept, parity 1	$\hat{\mu}_1$	-3.89	-3.71	-4.15	-3.97
Intercept, parity 2	$\hat{\mu}_2$	-3.25	-3.48	-4.06	-3.67
Intercept, parity 3	$\hat{\mu}_3$	-3.05	-3.05	-3.69	-3.16
Effect of mid lactation	$\hat{\alpha}_2$	-1.47	-1.90	-0.46	-0.87
Effect of late lactation	$\hat{\alpha}_3$	-0.87	-0.99	0.47	0.15
Standard deviation of week effect	$\hat{\sigma}_X$	0.32	0.38	0.34	0.35
Autocorrelation of week	$\hat{\rho}$	0.81	0.97	0.18	0.48
Standard error of the intercept, 1st parity	$s_{\mu 1}$	0.14	0.24	0.09	0.09
Standard error of the intercept, 2nd parity	$s_{\mu 2}$	0.14	0.12	0.08	0.09
Standard error of the intercept, 3rd parity	$s_{\mu 3}$	0.12	0.10	0.07	0.08
Standard error of mid lactation	$s_{\alpha 2}$	0.11	0.10	0.08	0.08
Standard error of late lactation	$s_{\alpha 3}$	0.12	0.10	0.08	0.08
Milk yield – parameter:					
Milk yield 60 days after calving, kg energy-corrected milk (ECM) (parity 1, 2, 3)	$\varphi_{1,l}$[1]	31.75, 41.77, 43.41	28.67, 40.70, 42.64	26.63, 32.74, 34.16	35.12, 50.58, 53.71
Slope over the first 60 days in milk (DIM), kg ECM (parity 1, 2, 3)	$\varphi_{2,l}$	0.13, 0.13, 0.17	0.11, 0.10, 0.11	0.10, 0.08, 0.11	0.28, 0.28, 0.34
Slope after 60 DIM, kg ECM (parity 1, 2, 3)	$\varphi_{3,l}$	- 0.02, - 0.06, - 0.08	- 0.02, - 0.06, - 0.07	- 0.03, - 0.06, - 0.06	- 0.02, - 0.08, - 0.10
Variance in the production potential of a cow (parity 1, 2, 3)	$\sigma^2_{A_l}$	21.52, 26.70, 35.19	20.99, 28.05, 38.54	15.61, 21.38, 28.23	24.07, 31.72, 45.77
Variance in local production effect (parity 1, 2, 3)	$\sigma^2_{X_l}$	9.32, 14.47, 19.90	7.16, 14.26, 16.53	7.46, 13.05, 15.99	10.54, 20.75, 29.07
Observational error (parity 1, 2, 3)	$\sigma^2_{v_l}$	2.44, 3.66, 7.22	3.93, 3.18, 4.39	1.99, 2.47, 3.50	1.48, 4.91, 6.55
Autocorrelation of local production effect (parity 1, 2, 3)	ρ_l	0.98, 0.98, 0.98	0.98, 0.98, 0.98	0.98, 0.98, 0.98	0.98, 0.98, 0.98

[1] l in refers to lactation number.

9.5 Manuscript V

Using state space models to monitor and estimate the effect of interventions on treatment risk and milk yield in Danish conventional dairy farms

Nanna Krogh Skjølstrup,[1*] Dorte B. Lastein,[1] Leonardo V. de Knegt,[1] Anders R. Kristensen,[1]

[1]Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, 1870 Frederiksberg C, Denmark

*Corresponding author: Nanna K. Skjølstrup, Department of Veterinary and Animal Sciences, Faculty of Health and Medical Sciences, University of Copenhagen, Grønnegårdsvej 2, DK-1870 Frederiksberg C, Denmark. Email: nannaks@sund.ku.dk.

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Abstract

Fast, flexible and internally valid analytical tools are needed to evaluate the effect of management interventions made on dairy farms to support decisions about which interventions to (dis)continue. The objective of this observational study was to demonstrate the use of state space models (SSMs) to monitor and estimate the effect of interventions on two specific outcomes: a dynamic linear model (DLM) evaluating herd-level milk yield and a dynamic generalized linear model (DGLM) evaluating treatment risk in a pragmatic pretest/posttest design under field conditions. The demonstration study is part of a Danish common learning project within the framework of veterinary herd health consultancy about reduction of antimicrobial usage and improved herd health running from March 2020 to May 2021. In two commercial herds, specific interventions were suggested by other project participants, and were implemented during the project period. The intervention for herd 1 was the application of teat sealers, implemented in August 2020. For herd 2, it was an adjustment of cubicles for cows in parity 2 and above, implemented from November 2020. A shift to robotic milking in October 2020 was also modelled as an intervention for herd 1, because the two intervention periods coincided. Data available from the Danish Cattle Database on obligatory registrations for individual cow movements, treatments assumed to include antimicrobials, and test day information on milk yield were used for model building and testing. Data from a three-year period before the project were used for baseline estimation, and data from the study period were used for monitoring and intervention testing. Herd bulk tank milk recordings were added to the dataset during the monitoring/intervention test period to increase the precision of the estimates in the DLM. The developed SSMs monitored herd-level milk yield and overall treatment risk throughout the study period in both herds. Furthermore, at the time of intervention, the SSMs estimated the effect on herd-level milk yield and treatment risk associated with the implemented intervention in each herd. The SSMs were used because they calibrate to herd conditions, take into account herd dynamics and auto-correlation, and provide insecurities of estimates. For herd 1, the intervention effect associated with application of teat sealers was inconclusive under the current SSM-application. For herd 2, no statistically significant changes in cow treatment risk or milk production were identified following the adjustment of cubicles. The demonstration of SSMs on observational data under field conditions shows how the interventions in this case had a non-specific onset of effect, were implemented during unstable times, and had varying coherence with the measured outcomes, which makes fully automated SSM analysis difficult. However, similar or expanded SSMs with both monitoring and effect estimation functions could serve as improved databased decision support tools for farmers (and veterinarians) to minimize the risk of misinterpretation of data due to confounding bias related to dynamics in dairy herds, if applied under the right conditions.

Key words: state space models, effect estimation and monitoring, milk yield, treatment risk, dairy farms

Introduction

Predicting the potential effects of management interventions made on a dairy farm can be difficult, as production conditions differ from farm to farm (Rose et al., 2016). Feeding, housing and milking systems differ, as well as strategies and management procedures. Therefore, similar input can result in positive or negative outcomes on different farms (Green et al., 2010), also described as heterogeneity of effects of a given intervention. Furthermore, assessing the causality of daily management interventions can be complex due to a lack of contemporary control groups, multiple concurrent changes in various procedures, and – to some extend – undetailed descriptions of implemented interventions. In addition, the outcome of the interventions can be influenced by a variety of herd-specific and time-dependent conditions, like variation in composition of the animal groups in relation to parity and lactation stage over time (Krogh, 2012). In order to evaluate the quantitative effects of interventions, farmers and advisors could benefit from valid estimates based on scientific methods that take into account context-specific dynamics and variation, instead of relying solely on raw data or descriptive analyses hereof. Such tools should preferably monitor relevant health and production outcomes simultaneously, be relatively quick to analyze selected and specific herd data and perhaps deliver results continuously (Østergaard et al., 2020). That way, interventions can be discontinued if they appear to have an unwanted influence on chosen herd health and production outcomes.

Decisions on what interventions to initiate (e.g. changed feeding composition or treatment regimen) and the evaluation of these interventions are often aspects of veterinary herd health consultancy (VHHC). Under Danish conditions, farmers must choose from different veterinary agreements to meet legal requirements, and a common learning or participatory approach, named "Stable School", is an example of a type of veterinary agreement that farmers can choose (Ministry of Environment and Food of Denmark, 2018). In a Stable School, a group of around 5-6 farmers meet at regular intervals throughout the year at each other's farms, with the purpose of sharing practical solutions to herd-specific problems (Lisborg et al., 2005). The veterinarian can be engaged as the facilitator of the Stable School and has responsibility for steering the discussions and ensuring that everyone participates on equal terms. Under Danish conditions, Stable Schools have been implemented and studied mainly in organic dairy herds (Vaarst et al., 2007). However, in this study, a Stable School for conventional dairy farmers was initiated as part of a larger study on common learning approaches within VHHC. During the Stable School meetings, interventions are expected to be suggested by the other participants and implemented at the participating farms. As with interventions planned during other types of veterinary advisory processes, the farmer and the veterinarian (or advisors in general) will be interested to know whether or not the intervention is beneficial for herd health and production or other relevant outcomes. Therefore, a demonstration of methods to continuously monitor and evaluate the effects of the interventions initiated during the Stable School or other VHHC situations is needed.

In an ideal scenario, interventions implemented on the different farms as a result of either classical VHHC or Stable School participation should result in increased health and/or production. In line with that, the overall goal of the Stable School of this study was "Improved health – fewer antimicrobials". Therefore, multiple outcomes need to be monitored simultaneously, to know whether the implemented interventions had the wanted effect in terms of the herd as a whole and the outcomes of interest (e.g. production, health, antimicrobial use (AMU)). Focusing specifically on the goal of the Stable School, it was necessary to identify proper outcomes related to herd health and AMU.

Under Danish conditions, antimicrobial consumption on herd level is monitored by the authorities as Animal Daily Doses (ADD) per 100 animals per day (Jensen et al., 2004). However, this type of inventory is complicated to use as a dynamic proxy for AMU under real-time VHHC settings. This is because ADD per 100 animals per day is calculated on a monthly basis and fluctuates with medicine purchasing patterns instead of use patterns (Dupont, 2016). Therefore, an alternative proxy for monitoring and effect estimation on AMU was needed, due to the focus on field conditions in this study. For that reason, the estimation of treatment risk based on treatment registrations (the weekly number of registered treatment days) was used as a proxy for AMU. These data are available to farmers and veterinarians through the national Danish Cattle Database (DCD) and for that reason, treatment risk was applicable for monitoring and effect estimation in a VHHC setting. Treatment risk as a proxy for AMU represents management choices in relation to administration of drugs, i.e. farmer- and veterinarian-specific treatment threshold, and not actual AMU (active substance per unit). However, for the present demonstration purpose, we assume that lower treatment frequency correlates to reduction in active substance.

Since the focus of the Stable School in this study was both on AMU and herd health, milk yield as a proxy for production level (and herd health indirectly) was used for monitoring and effect estimation to get a holistic perspective of the implemented interventions' effect. Data on milk yield (test day information) are likewise available to farmers and veterinarians through the DCD.

Issues related to the low internal validity of data, which both simpler descriptive analysis and advanced models face, must be kept in mind in all cases using observational analysis of existing data, e.g. treatment registrations (Kristensen et al., 2008). However, the present study will focus on the demonstration of methods for analysis rather than internal data validity.

Different analytical methods to estimate the effects of interventions have been proposed over time. To demonstrate the causal effect of an intervention, randomized control trials are needed, yet these are often difficult to apply to real-life situations (Lastein, 2012). Currently, the decision support tools used on Danish dairy farms are often based on key performance figures, such as plots of milk yield and number of treatments over time, benchmarking, and in some cases multivariable analysis, simulations and time series analysis such as statistical process control (De Vries and Reneau, 2010; Krogh, 2012). However, these tools all have limited flexibility in terms of taking into account farm-specific variation and auto-correlation (e.g. dependencies between test day results and cows in adjacent parities), and the results may therefore be biased. Previous studies have suggested the use of state space models (SSMs) with Kalman filtering for monitoring production data, as demonstrated in the EVolutionary OPeration principle (i.e. series of ongoing herd trialing during normal commercial production) (Østergaard et al., 2020), and for estimating the effect of an intervention in different study designs. SSMs are proven effective for these purposes because they address the above mentioned farm-specific variation and auto-correlation.

Besides that, they provide forecasting values, which means that future performance can be forecasted in a monitoring perspective. In addition, credible intervals can be estimated for all parameters of the model, thus making assessment of deviation more precise (West and Harrison, 1997). Stygar et al. (2017) developed a dynamic linear model (DLM) for estimating the effect of an intervention on milk yield at two dairy farms with different milking systems – an automatic milking system (AMS) and a milking parlor –, and in a controlled trial set-up and pretest/posttest design. Furthermore, SSMs have been developed for monitoring reproduction records for cattle (Cornou et al., 2014), bulk tank somatic cell count (Thysen, 1993), and milk yield (Van Bebber et al., 1999), and for predicting mastitis (Jensen et al., 2016). Furthermore, several SSMs have been developed for monitoring mortality rate (Bono et al., 2014), litter size (Bono et al., 2012), and farrowing rate (Bono et al., 2013) in pig production. However, no dynamic generalized linear model (DGLM) has been developed to monitor and estimate the effect of an intervention on treatment risk within dairy herds. Nor have SSMs, to our knowledge, been used to study and estimate the effects of an intervention on two different outcomes simultaneously, resembling a "stop-light on multiple outcome parameters" for the implemented intervention if used during an ongoing VHHC process under field conditions.

The objective of this paper was to outline perspectives of application of SSMs to 1) graphically monitor and 2) statistically test and hence evaluate the effects of interventions made in a dairy context in a pretest/posttest design under field conditions.

Materials and methods

The study complied with relevant Danish and International standards and guidelines for research ethics, and approval was granted by the Research Ethics Committee for Science and Health, University of Copenhagen (ReF: 504-0137/20-5000). In addition, the project complied with the General Data Protection Regulation, and approval was granted (Ref. no.: 514-0312/19-3000). Written consent to extract and analyze data from the DCD for the participating herds was given by the farm owners. The study was reported in line with the STROBE-vet Statement (Sargeant et al., 2016).

Data from herds

Two Danish conventional dairy herds were enrolled in a Stable School (with three additional participants from each their farm) running from March 2020 to April 2021. These two herds with each their example of an intervention completed during the Stable School period will serve as cases for demonstration. Herd 1 had 180 Holstein cows and changed from conventional milking to AMS during the Stable School period, whereas Herd 2 was a 270 Holstein cows AMS herd.

Historical data used for modelling

Data dating back 3 years were collected from each herd before the start of the Stable School (March 1, 2017 to February 29, 2020) to create a baseline week-by-week dataset for treatment risk and a day-to-day dataset for milk yield for each herd. Cow-level data available from the DCD included information on birth date, herd entry and exit date, calving dates, dry-off dates, daily antimicrobial treatment registrations (all medical treatments are registered on cow level on a day-to-day basis, being compulsory according to Danish legislation), and test day recordings of milk yield, and these were collected approximately 11 times annually per herd. Data on young stock were not included.

Farmers are not obliged to record the date of dry-off, so the cows for which this information was lacking were excluded from the dataset, as their point in lactation could not be determined. Possible reasons for missing registrations of dry-off dates included abortion or inconsistent or faulty registrations by the farmer. Based on the exclusion criteria, 10 out of 421 cows present during the historical and intervention period were excluded from the dataset for herd 1, and 22 out of 685 cows were excluded from the dataset for herd 2.

The dataset included registrations of medical treatments made by farmers or veterinarians that were expected to include antimicrobials. Therefore, some of the selected treatment registrations might include only pain medication. In summary, the registrations included udder-related treatments (clinical and subclinical mastitis, dry cow treatment) and other types of diseases (metritis, retained placenta, infectious gastrointestinal disorders, infectious locomotor disorders, pneumonia, urinary tract infections). Details of the type of disease registrations are omitted here, however udder disease remains the most frequent indication for antimicrobial treatment of dairy cows under Danish conditions (Korsgaard et al., 2020). Therefore, if a cow received multiple treatments on a certain day, priority was given to registrations of udder treatment. This happened to one case in herd 1, and two cases in herd 2. In total, 776 treatment days for herd 1 and 1,385 treatment days for herd 2 were available for the model-building dataset. Depending on the analysis, either all medical (antimicrobial) treatments or only udder-related treatments were chosen as the outcome. This differentiation will be specified in the text.

A total of 4,647 individual observations from 325 cows in herd 1 and 7,440 individual observations from 563 cows in herd 2 in relation to test day recordings on milk yield were available for the model-building dataset. Energy-Corrected Milk (ECM) yield was calculated by correcting the raw milk yield for protein and fat content in test recordings according to the following equation (Sjaunja et al., 1990):

$$ECM\ (kg) = Milk\ (kg)\ x\ ((383\ x\ fat\% + 242\ x\ protein\% + 783.2)\ /\ 3{,}140)$$

Interventions and justification

In the Stable School setting, farmers selected a herd-specific management intervention that they wanted to implement. The intervention was selected among a series of potential interventions proposed by the other farmers in the Stable School, as described earlier.

Herd 1

For herd 1, the specific intervention was extended use of teat sealers in relation to dry-off from August 2020 onwards. Before the intervention, teat sealers were applied inconsistently and less frequently, however, after August 2020, they were applied for all cows at dry-off, either in combination with antimicrobials or alone. Teat sealers alone were applied in cases with negative bacteriological culture of milk simples from cows at dry-off (*Enterococcus* growth, no growth of *Streptococcus agalactiae* or *Staphylococcus aureus*, or <5 colonies of other typical udder pathogens) or cows that had a SCC below 200,000 (cultured on veterinary clinic laboratory).

Application of teat sealers was hypothesized to have a positive effect on udder health, as fewer bacteria can enter the teat canal during the dry-off period. The treatment frequency of subclinical and clinical mastitis during the dry period and start of lactation was therefore expected to decrease and subsequently lead to a potential increase in milk yield (Crispie et al., 2004; Berry and Hillerton, 2007; McParland et al., 2019). This theory was evaluated by investigating the effect of a consistent use of teat sealers in herd 1 in a pretest/posttest design on the treatment frequency of udder diseases and milk yield.

However, herd 1 changed from a milking parlor to AMS during the intervention period (October 1, 2020), and such a change in milking system could influence the milk yield negatively (Tse et al., 2018) and have a negative influence on udder health (increase treatment risk). This could obscure any potential positive effect on milk yield or negative effect on treatment risk gained by applying teat sealers. Therefore, the initiation of robots was modeled as a second intervention in herd 1, mimicking concurrent events under real-life herd conditions. This was done in order to differentiate between the effects of the two different interventions, which were implemented in short succession. For the purpose of this study, only the effect of applying teat sealers will be reflected upon in terms of whether the intervention should be continued or not, as teat sealer application was initiated as part of the Stable School and was the focus of the participatory advisory process. Additive intervention effects were assumed; the second intervention (AMS) included data up to the time point when the robots were initiated and corrected for the teat-sealer intervention.

The intervention effect was evaluated over a four-month period (August 1, 2020 to December 1, 2020) after the first intervention (teat sealers), and a two-month period after the second "intervention" (AMS) (October 1, 2020 to December 1, 2020). This timescale was chosen to provide a long enough period so that an effect of the teat sealer application and shifting to AMS could be expected, while also being short enough not to violate the assumption that the state after the interventions was similar to the state before the interventions.

The onset of the intervention effect of teat sealer application was set to be gradual over an eight-week period (August 1, 2020 to October 1, 2020) in relation to udder treatment risk. In relation to the effect on milk production, the full intervention effect was modelled as the cows completed their dry periods after the teat sealers were applied. In terms of the effect on udder treatment risk, we expected some effect to be seen shortly after application among dry cows, as fewer cases of dry cow mastitis would be expected. However, according to treatment registrations in herd 1 from the DCD (not shown), there were no registered cases of dry cow mastitis during the Stable School period. Therefore, this fast onset of effect was not expected to be seen. Instead, an effect was expected to be seen among fresh cows that had teat sealers applied when they were dried off, as we would expect fewer cases of new mastitis infections at the beginning of the lactation period. As herd 1 had around 180 cows, approximately 10-20 cows would be expected to calve each month, implying that the effect of applying teat sealers would be based on a slowly increasing number of cases. Since the dry period length is around 50 days for herd 1 (data not shown), we expected the effect on udder treatment risk of applying teat sealers to be evident after approximately 2 months.

Herd 2

For herd 2, the specific intervention investigated in this study was the adjustment of cubicles by heightening the position of the loops on the supporting posts during November 2020 (the partition, head rail and neck rail height was increased). Only sections with cows in parity ≥2 were adjusted, and it was done gradually over the one-month period. Higher-positioned (permissive) neck rails have been associated with eased lying down movements of cows (Dirksen et al., 2020; Gieseke et al., 2020). Restricted neck rail placements have been found to result in a larger number of cows standing with their front hooves only in the stall and an increased occurrence of locomotor disorders (Bernardi et al., 2009; Fregonesi et al., 2009; Chapinal et al., 2013). Therefore, heightening the position of the loops in herd 2 was hypothesized to decrease treatment frequency of claw/leg-related diseases, as the lying down behavior and time spent standing with only front hooves in the stall would be reduced. In relation to milk production, diverging effects were expected. Dirty udders have an impact on the prevalence of mastitis (Schreiner and Ruegg, 2003), yet studies have reported differing results relating to the association between neck rail position and udder cleanliness (Bernardi et al., 2009; Gieseke et al., 2020). Milk production could be increased due to fewer lame cows (thus producing more milk), yet it may also decrease due to more cases of mastitis (if cows defecate more in cubicles after adjustment, thereby resulting in dirty udders and a higher risk of mastitis). These theories were evaluated in a pretest/posttest design, including all antimicrobial treatments to evaluate the effect on overall treatment risk.

We identified no concurrent changes in farm management in herd 2 that could distort the result of the effect estimation of the adjustment of cubicles-intervention and therefore should be modelled separately.

The intervention effect was evaluated over a two-month period (November 1, 2020 to January 1, 2021). This timescale was chosen to provide a long enough period so that an effect of the adjustment of cubicles could be expected, while also being short enough not to violate the assumption that the state after the intervention was similar to the state before the intervention.

The onset of the intervention effect of the adjustment of cubicles was uncertain. This was because the farm personnel had to adjust the cubicles on an ongoing basis when time allowed. The stress of having farm personnel working on the heightening of the loops among the cows could have an immediate negative effect on milk production. For some diseases, e.g. cases of environmental mastitis, an effect could be expected within a relatively short period after the cubicles are adjusted (cows may defecate more in their cubicles, thus affecting udder cleanliness, potentially leading to an increased prevalence of mastitis and decreased milk production). In relation to locomotive disorders, a slower onset of effect was expected as chronic claw disorders will not disappear within a short period, however, the number of new cases would be expected to decrease rather quickly. Overall, we hypothesize that an effect of adjusting the cubicles should be seen within a two-month period after initiation.

Data used for testing

All data editing and modelling was done in R (Version 4.04, R Core Team 2021, https://www.R-project.org/). The data structure used for testing was the same as for model building, but the data were collected from March 1, 2020 to May 1, 2021 (the Stable School period). Furthermore, for the milk yield model, the test day recordings were supplemented with information on herd bulk tank milk from each herd, corrected for discharged milk, as described in Stygar et al. (2017), in order to increase the precision of the estimates of milk yield. In the test dataset, a total of 2,131 and 3,006 individual observations of test day recordings of milk yield were supplemented with 214 and 215 observations of herd bulk tank milk for herds 1 and 2, respectively.

The treatment risk model

Treatment is a binary trait and is therefore modelled on the logistic scale. A DGLM assumes that all random terms are drawn from a multivariate binomial distribution and was therefore used to model the binary outcome "treatment risk". The risk of treatment was assumed to depend on the cow's parity and stage of lactation. Therefore, a model to estimate the effect of an intervention on treatment risk for cows in a herd should be adjusted for these systematic effects by taking into account their development over time.

We constructed a multivariate DGLM to describe treatment risk using historical data. A DGLM consists of an observation equation (Eq. 2.1) and a system equation (Eq. 2.3 and 2.5) (West and Harrison, 1997). Weekly observations of treatments were used to update the two herd profiles.

Observation equation and system equation

Let K_{nst} be the number of treatments out of N_{nst} cows at risk for parity n ($n = 1, 2, \geq 3$), stage of lactation s ($s = 1, 2, 3$) in week t. The stage of lactation was categorized according to days from calving, where $s1$ is before day 60 after calving, $s2$ is day 61-280 after calving, and $s3$ is after day 280 after calving. The categories were determined according to the expected pattern of treatment during lactation and dry-off. The observation equation linking the observations to the parameters becomes

$$K_{nst} = \mathcal{B}(N_{nst}, p_{nst}), \qquad 2.1$$

where $\mathcal{B}$ denotes the binomial distribution, p_{nst} is the probability of treatment for an individual cow of parity n, stage of lactation s, and in week t. Let $\eta_{nst} = \text{logit}(p_{nst})$ be the logistic transformation of the probability, giving

$$\eta_{nst} = \mu_n + \alpha_s + X_t \qquad 2.2$$

where μ_n is an intercept for parity n, α_s is a systematic effect of stage of lactation (with $\alpha_1 = 0$), and $X_t \sim N(0, \sigma_X^2)$ is a temporary random week effect that evolves over time according to the system equation

$$X_t = +\rho X_{t-1} + \epsilon_t, \qquad 2.3$$

where the parameter ρ represents the auto-correlation within the herd and $\epsilon_t \sim N(0, (1-\rho^2)\sigma_X^2)$ is an error term assumed to be normally distributed.

The parameter vector is defined as $\theta_t = (\mu_1, \mu_2, \mu_3, \alpha_2, \alpha_3, X_t)'$, corresponding to the treatment risk for the three different parities and lactation stages in week t. In matrix notation, the system equation becomes

$$\begin{pmatrix}\mu_1\\ \mu_2\\ \mu_3\\ \alpha_2\\ \alpha_3\\ X_t\end{pmatrix} = \begin{pmatrix}1 & 0 & 0 & 0 & 0\\ 0 & 1 & 0 & 0 & 0\\ 0 & 0 & 1 & 0 & 0\\ 0 & 0 & 0 & 1 & 0\\ 0 & 0 & 0 & 0 & \rho\end{pmatrix}\begin{pmatrix}\mu_1\\ \mu_2\\ \mu_3\\ \alpha_2\\ \alpha_3\\ X_{t-1}\end{pmatrix} + \begin{pmatrix}0\\ 0\\ 0\\ 0\\ 0\\ \epsilon_t\end{pmatrix} \quad 2.4$$

where the number of rows and columns corresponds to the size of θ_t. The system equation shows how the parameter values may change over time and is expressed as follows in matrix notation:

$$\theta_t = G\theta_{t-1} + w_t. \quad 2.5$$

where the system matrix G (as illustrated in equation 2.5) is constant, and $w_t \sim N(\underline{0}, W_t)$ has $\underline{0}$, which is a vector of zeros, and W_t, which is a variance-covariance matrix. Furthermore, Eq. 2.5 becomes

$$\begin{pmatrix}\eta_{11t}\\ \eta_{12t}\\ \eta_{13t}\\ \eta_{21t}\\ \eta_{22t}\\ \eta_{23t}\\ \eta_{31t}\\ \eta_{32t}\\ \eta_{33t}\end{pmatrix} = \begin{pmatrix}1 & 0 & 0 & 0 & 0 & 1\\ 1 & 0 & 0 & 1 & 0 & 1\\ 1 & 0 & 0 & 0 & 1 & 1\\ 0 & 1 & 0 & 0 & 0 & 1\\ 0 & 1 & 0 & 1 & 0 & 1\\ 0 & 1 & 0 & 0 & 1 & 1\\ 0 & 0 & 1 & 0 & 0 & 1\\ 0 & 0 & 1 & 1 & 0 & 1\\ 0 & 0 & 1 & 0 & 1 & 1\end{pmatrix}\begin{pmatrix}\mu_1\\ \mu_2\\ \mu_3\\ \alpha_2\\ \alpha_3\\ X_t\end{pmatrix} \quad 2.6$$

where n_t^f is the full vector of logistic transforms of the treatment probabilities and the design matrix F' is constant as long as there are cows in all nine observation groups. In simplified notation:

$$\eta_t^f = F'\theta_t. \quad 2.7$$

Notation

Matrices of the equations

In practice, it may be that there are no cows in an observation group (i.e. a combination of parity and stage of lactation where $N_{nst} = 0$). The corresponding rows of η_t^f and F' are thus omitted. The system variance-covariance matrix describes the evolution variance and covariance of each of the parameters and has zeros except for the element referring to X:

$$W = \begin{pmatrix}0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & 0\\ 0 & 0 & 0 & 0 & 0 & (1-\rho^2)\sigma_X^2\end{pmatrix}. \quad 2.8$$

This implies that the true parameters describing lactation and stage of lactation effects are assumed to be constant. Only the random week effect may fluctuate over time.

Initial distribution

For a full specification of the DGLM, the initial distribution of the vector of parameter, $\theta \sim N(m_0, C_0)$ was learned from data. The initial vector of parameters, m_0, consisted of the mean values of herd effects for different parities and stages of lactation, and zero for the parameter representing the week effect:

$$m_0 = \begin{pmatrix} \hat{\mu}_1 \\ \hat{\mu}_2 \\ \hat{\mu}_3 \\ \hat{\alpha}_2 \\ \hat{\alpha}_3 \\ 0 \end{pmatrix}, \quad 2.9$$

where, for instance, $\hat{\mu}_1$ is the estimated intercept for parity 1 and start of lactation, and $\hat{\alpha}_2$ is the effect of mid lactation for all parities. For C_0, the initial variance-covariance matrix, the following structure was assumed:

$$C_0 = \begin{pmatrix} s_{\mu_1}^2 & 0 & 0 & 0 & 0 & 0 \\ 0 & s_{\mu_2}^2 & 0 & 0 & 0 & 0 \\ 0 & 0 & s_{\mu_3}^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & s_{\alpha_2}^2 & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{\alpha_3}^2 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sigma_X^2 \end{pmatrix}, \quad 2.10$$

Where 0 represents matrices only consisting of zeros; $s_{\mu_1}^2 - s_{\mu_3}^2$ represent standard errors of the estimates of the intercepts for parity 1-3; $s_{\alpha_2}^2$ and $s_{\alpha_3}^2$ represent standard errors of the estimates of the intercepts for mid and late lactation; σ_X^2 represents the standard deviation of the week effect.

Estimation of initial variables and variance components

The model was fitted to the historical data using the glmmTMB package in R (Brooks et al., 2017). The results are shown in Table 1. Model assumptions were checked by plotting the forecast errors.

Table 1. Estimated initial variables and variance components based on historical data.

Parameter	Symbol	Herd 1	Herd 2
Intercept, parity 1	$\hat{\mu}_1$	-3.89	-3.97
Intercept, parity 2	$\hat{\mu}_2$	-3.25	-3.67
Intercept, parity 3	$\hat{\mu}_3$	-3.05	-3.16
Effect of mid lactation	$\hat{\alpha}_2$	-1.47	-0.87
Effect of late lactation	$\hat{\alpha}_3$	-0.87	0.15
Standard deviation of week effect	$\hat{\sigma}_X$	0.32	0.35
Auto correlation of week	$\hat{\rho}$	0.81	0.48
Standard error of intercept, parity 1	$s_{\mu 1}$	0.14	0.09
Standard error of intercept, parity 2	$s_{\mu 2}$	0.14	0.09
Standard error of intercept, parity 3	$s_{\mu 3}$	0.12	0.08
Standard error of mid lactation	$s_{\alpha 2}$	0.11	0.08
Standard error of late lactation	$s_{\alpha 3}$	0.12	0.08

Modelling intervention effect

Suppose that an intervention (e.g. adjustment of cubicles) takes place in week t_I. Then assume that there is an adaption period of n_α weeks. The DGLM needs to be extended with a parameter for the intervention effect. In other words, the parameter vector now holds seven elements $\theta_t = (\mu_1, \mu_2, \mu_3, \alpha_2, \alpha_3, X_t, \lambda)'$ where λ is the (full) intervention effect after the adaption period.

The matrices are adjusted accordingly:

$$G = \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & \rho & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{pmatrix}, \tag{2.11}$$

$$W = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & (1-\rho^2)\sigma_X^2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}, \tag{2.12}$$

$$m_0 = \begin{pmatrix} \hat{\mu}_1 \\ \hat{\mu}_2 \\ \hat{\mu}_3 \\ \hat{\alpha}_2 \\ \hat{\alpha}_3 \\ 0 \\ 0 \end{pmatrix}, \tag{2.13}$$

$$C_0 = \begin{pmatrix} s_{\mu_1}^2 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & s_{\mu_2}^2 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & s_{\mu_3}^2 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & s_{\alpha_2}^2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{\alpha_3}^2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & \sigma_X^2 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & \sigma_\lambda^2 \end{pmatrix}, \tag{2.14}$$

where σ_λ^2 is the prior variance of the intervention effect.

The design matrix now depends on the week as follows:

$$F' = \begin{cases} \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 1 & 0 \\ 1 & 0 & 0 & 1 & 0 & 1 & 0 \\ 1 & 0 & 0 & 0 & 1 & 1 & 0 \\ 0 & 1 & 0 & 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 & 1 & 1 & 0 \\ 0 & 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 0 & 1 & 1 & 0 & 1 & 0 \\ 0 & 0 & 1 & 0 & 1 & 1 & 0 \end{pmatrix}, t < t_I \\ \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 1 & (t - t_I + 1)/n_\alpha \\ 1 & 0 & 0 & 1 & 0 & 1 & (t - t_I + 1)/n_\alpha \\ 1 & 0 & 0 & 0 & 1 & 1 & (t - t_I + 1)/n_\alpha \\ 0 & 1 & 0 & 0 & 0 & 1 & (t - t_I + 1)/n_\alpha \\ 0 & 1 & 0 & 1 & 0 & 1 & (t - t_I + 1)/n_\alpha \\ 0 & 1 & 0 & 0 & 1 & 1 & (t - t_I + 1)/n_\alpha \\ 0 & 0 & 1 & 0 & 0 & 1 & (t - t_I + 1)/n_\alpha \\ 0 & 0 & 1 & 1 & 0 & 1 & (t - t_I + 1)/n_\alpha \\ 0 & 0 & 1 & 0 & 1 & 1 & (t - t_I + 1)/n_\alpha \end{pmatrix}, t_I \le t < t_I + n_\alpha \\ \begin{pmatrix} 1 & 0 & 0 & 0 & 0 & 1 & 1 \\ 1 & 0 & 0 & 1 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 & 1 & 1 & 1 \\ 0 & 1 & 0 & 0 & 0 & 1 & 1 \\ 0 & 1 & 0 & 1 & 0 & 1 & 1 \\ 0 & 1 & 0 & 0 & 1 & 1 & 1 \\ 0 & 0 & 1 & 0 & 0 & 1 & 1 \\ 0 & 0 & 1 & 1 & 0 & 1 & 1 \\ 0 & 0 & 1 & 0 & 1 & 1 & 1 \end{pmatrix}, t \ge t_I + n_\alpha \end{cases} \qquad 2.15$$

For herd 1, two interventions were modeled (application of teat sealers and initiation of milking robots). This was handled in the same way as for one intervention, with an increase in the size of the parameter vector and the matrices.

Weekly updating

As the model is multivariate and the outcome data is binary, the Kalman filter with Taylor expansion was used as the updating technique. This method is described in Appendix A in Bono et al. (2013).

The milk yield model

Milk yield is a normally distributed outcome and should therefore be modelled by a DLM. This is because a DLM assumes that all random terms are drawn from a multivariate normal distribution. A model to estimate the effect of an intervention on milk yield for cows in a pretest-posttest design (here teat sealers/AMS for herd 1 and cubicle design for herd 2) was adapted from Stygar et al. (2017). The DLM for milk yield was adjusted according to the cow's parity level and stage of lactation, as these were assumed to influence milk yield levels. Furthermore, herd milk yield was modelled as a two-piece linear function, as described by Bennedsgaard et al. (2003). This lactations curve model was used, as it is an integrated part of the Danish VHHC system.

A full description of the DLM can be found in the paper by Stygar et al. (2017), as the model was applied in the exact same way in this study, except for one necessary adjustment. This adjustment was due to the fact that test day information (supplemented with herd bulk tank milk) appeared to be an insufficient data inflow for this study. The model in this study used the data that was readily available for the two herds through the DCD, without having to manually extract data from the milking robots, making the data flow more applicable in a general Danish field context.

The insufficient data caused the auto-correlation, ρ, of the local production effect, X_{ijd}, to be close to 1, thus leading to an incorrect estimation of the variance in the production potential of a cow, A_{ij}. This means that the explained variance of the model could not be estimated in separate. To solve that issue, an approach previously used by Nielsen et al. (2010) was applied: ρ was set to 0.98, and the estimation of the variance components was run without the correlation structure, i.e. without the variance in the local production effect, σ_X, and auto-correlation of the local production effect, ρ. The variance in the local production effect, σ_X, was calculated assuming that the covariance between yields 200 days apart is $\sigma_A + \rho^{200} * \sigma_X$ and that A_{ij} contributes by 99% and X_{ijd} by 1%.

The model was fitted to the historical data using the nlme package in R (Pinheiro et al., 2021). Model assumptions were checked by plotting the forecast errors.

Table 2. Milk yield parameters estimated for herd 1 (standard deviation in parentheses) based on historical data.

Parameter	Symbol[1]	Parity 1	Parity 2	Parity 3
Milk yield 60 days after calving, kg ECM[2]	$\varphi_{1,l}$	31.75 (0.16)	41.77 (0.32)	43.41 (0.28)
Slope over the first 60 DIM[3], kg ECM	$\varphi_{2,l}$	0.13 (0.00006)	0.13 (0.0001)	0.17 (0.0001)
Slope after 60 DIM, kg ECM	$\varphi_{3,l}$	- 0.02 (0.000004)	- 0.06 (0.000009)	- 0.08 (0.000009)
Variance in the production potential of a cow	$\sigma^2_{A_l}$	21.52	26.70	35.19
Variance in local production effect	$\sigma^2_{X_l}$	9.32	14.47	19.90
Observational error	$\sigma^2_{v_l}$	2.44	3.66	7.22
Auto correlation of local production effect	ρ_l	0.98	0.98	0.98

[1]l refers to lactation number. [2]Energy-corrected milk. [3]Days in milk.

Table 3. Milk yield parameters estimated for herd 2 (SD in parentheses) based on the historical data.

Parameter	Symbol[1]	Parity 1	Parity 2	Parity 3
Milk yield 60 days after calving, kg ECM[2]	$\varphi_{1,l}$	35.12 (0.11)	50.58 (0.24)	53.71 (0.27)
Slope over the first 60 DIM[3], kg ECM	$\varphi_{2,l}$	0.28 (0.00003)	0.28 (0.00009)	0.34 (0.0001)
Slope after 60 DIM, kg ECM	$\varphi_{3,l}$	- 0.02 (0.000003)	- 0.08 (0.000007)	- 0.10 (0.000009)
Variance in the production potential of a cow	$\sigma^2_{A_l}$	24.07	31.72	45.77

Variance in local production effect	$\sigma^2_{X_l}$	10.54	20.75	29.07
Observational error	$\sigma^2_{v_l}$	1.48	4.91	6.55
Auto correlation of local production effect	ρ_l	0.98	0.98	0.98

[1]l refers to lactation number. [2]Energy-corrected milk. [3]Days in milk.

Figure 1 and Figure 2 show a graphical presentation of the herd lactation curves, resulting from modeling those curves as two linear functions with two parameters each. The milk yield on day 60 and the parameters for the slope before and after day 60 for the two herds can be seen in Table 2 and Table 3. In total, there are nine valid lactation curve parameters for each herd. The data in the tables were used to set the initial distribution of the multivariate dynamic linear model for milk yield.

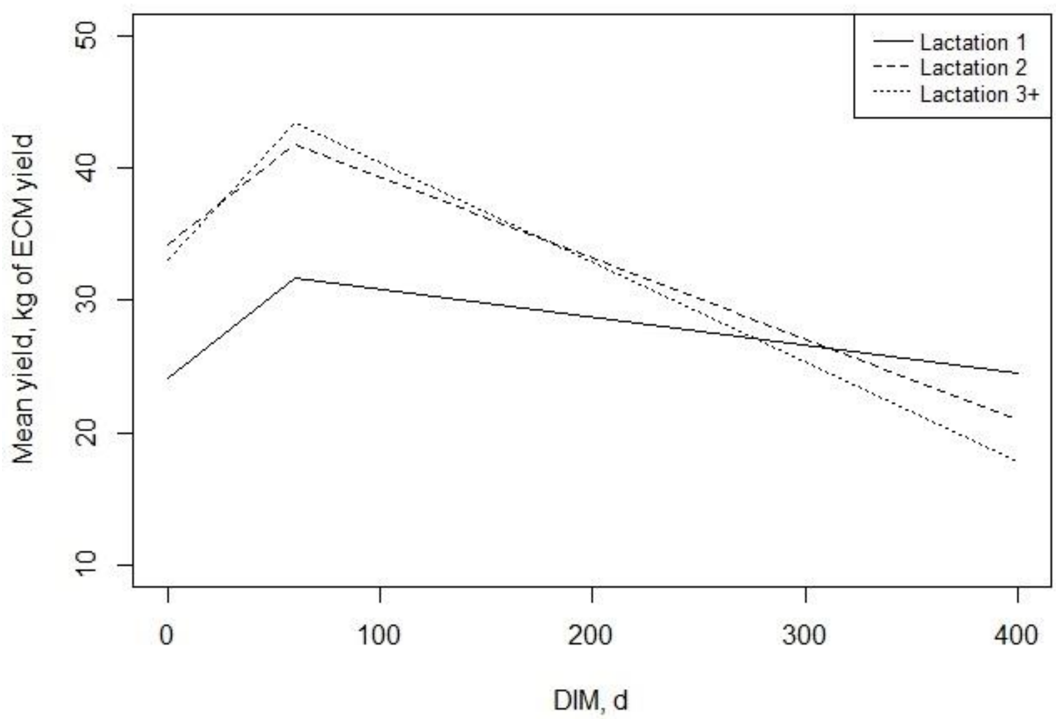

Figure 1. Lactation curve for herd 1 (daily milk yield in kg energy-corrected milk (ECM) as a function of days in milk) for all parities individually. Estimated based on the historical data. Modeled based on two linear functions as in Stygar et al. (2017) and Bennedsgaard et al. (2003).

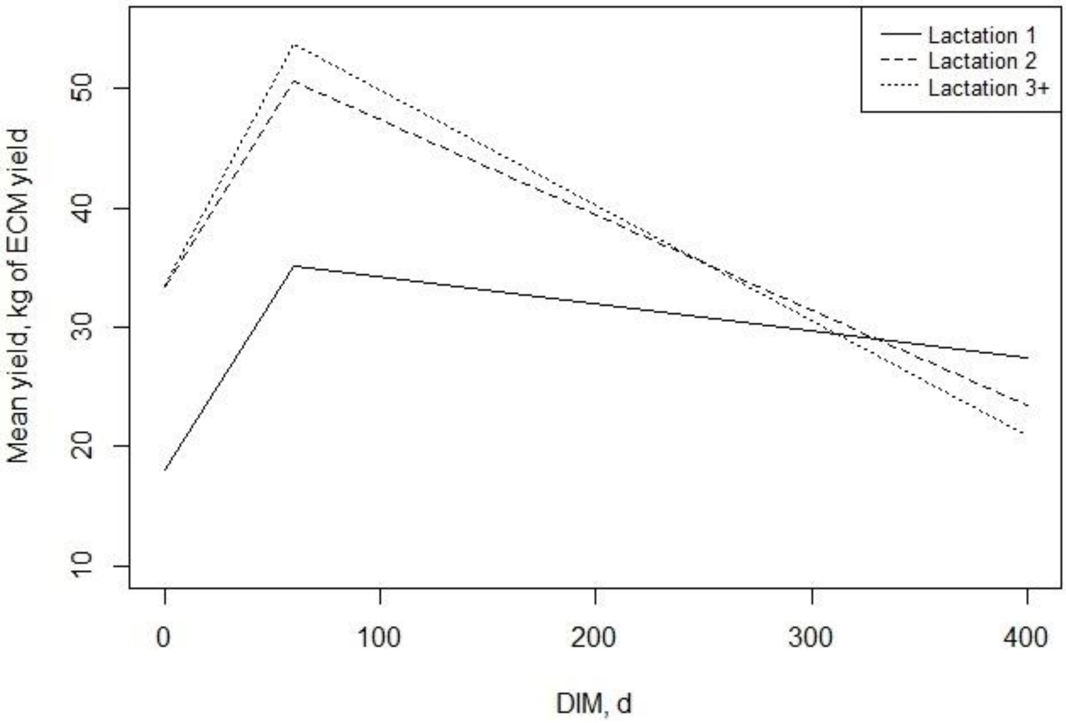

Figure 2. Lactation curve for herd 2 (daily milk yield in kg energy-corrected milk (ECM) as a function of days in milk) for all parities individually. Estimated based on the historical data. Modeled based on two linear functions as in Stygar et al. (2017) and Bennedsgaard et al. (2003).

Monitoring treatment risk and milk yield

The developed models can also be used for retrospective monitoring purposes. Smoothened means of the parameter vector, θ_t , and smoothened variance-covariance, W_t, can be obtained by excluding the intervention extension (setting the intervention to zero) when running the Kalman filter and the Kalman smoother. The filtered results are smoothened to include all available data, in order to evaluate results retrospectively.

For the treatment risk model, the means of the parameter vector include parameters for each of the three parities and for each of the three stages of lactation, as well as the week effect. To facilitate interpretation of the parameter values, they can be changed from a logistic to a probabilistic scale (i.e. $p_{nst} = (\exp(-\theta_{ns}) + 1)^{-1}$). These can then be plotted to monitor the herd-level probability of treatment for cows of different parities and stages of lactation in a specific herd retrospectively.

When interpreting a monitoring graph for treatment risk, fluctuations in probability of treatment cannot be attributed to the number of cows present in the herd during the period, nor their distribution across parity and stage of lactation, as the DGLM adjusts for those effects. As auto-correlation is handled at herd level, the model also indirectly adjusts for seasonal effects on treatment risk. Therefore, seasonal effects and auto-correlation do not explain fluctuations in probability of treatment. The effects of parity and stage of lactation are assumed to be constant, and auto-correlation is handled as a herd effect, with no interaction between parities and stages of lactation assumed in this study. Therefore, interpretation of fluctuations should only be considered at herd level. The uncertainties in the estimated intercepts for the different parities and stages of lactation are shown by the means of the standard errors in Table 1.

For the milk yield model, the means of the parameter vector first include the nine parameters describing the shape of the lactation curves at time t, and secondly, all the parameters describing the individual cows present in the herd on a given day, i.e. A_t: the cow production potential and X_t: the local production effect. The sum of these can then be plotted to retrospectively monitor the extent to which the daily herd-level milk yield for a specific herd deviates from that herd's standard milk yield level.

Like in the treatment risk monitoring graphs, when interpreting a monitoring graph for milk yield, fluctuations in the sum cannot be attributed to the number of cows present in the herd at the given time, nor to the distribution across parities or stages of lactation, as these effects are accounted for in the model. Furthermore, auto-correlation at cow level is assumed, thus accounting for a seasonal effect, which is why neither auto-correlation nor seasonal effects explain fluctuations in milk yield.

The monitoring graphs for the two herds will be illustrated in the beginning of the following result section, to give an overview of the milk yield and probability of treatment levels in the two herds during the whole Stable School period, before zooming in on specific intervention periods. Furthermore, the results of the monitoring graphs, in combination with knowledge on ongoing changes in the herds, guided the choice on whether additional interventions should be modelled in each herd.

Results

The results are presented for each herd subsequently. First, the monitoring graphs are presented; afterwards, the statistical test of the effect of the herd-specific intervention(s) on treatment risk (udder/overall) and milk production are presented.

Herd 1

Monitoring treatment risk and milk yield

Figure 3 illustrates the development in herd-level treatment risk for herd 1 during the Stable School period (March 2020 to May 2021). The herd-level probability of treatment fluctuated from 0.5-4% during certain periods (lowest levels) to 1-7% in other periods (highest levels), but ended up at approximately the same level as at the beginning of the Stable School period. An increasing trend in herd-level probability of treatment was observed from March 2020 to July 2020, followed by an overall decreasing trend for the rest of the period (with a number of short periods of increase in between). In August 2020, when the intervention (application of teat sealers) was initiated, there was a short peak in the probability of treatment, followed by a decrease. In October 2020, when the second "intervention" (shifting to AMS) was initiated, there was a decreasing trend in the probability of treatment.

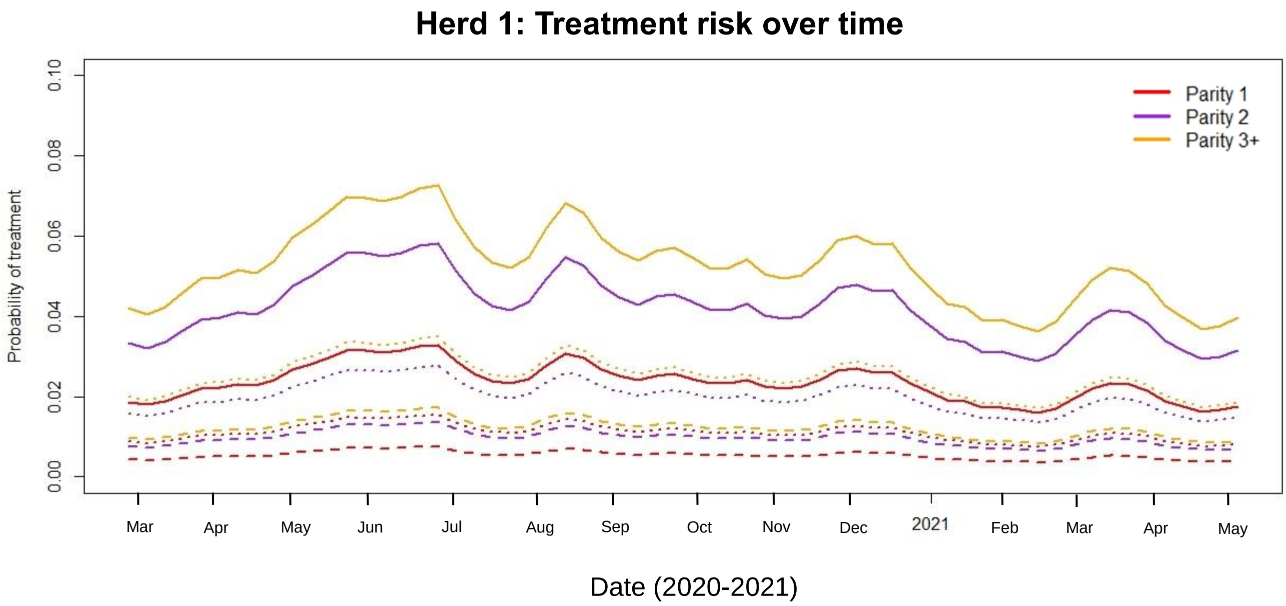

Figure 3. Dynamic generalized linear model monitoring treatment risk in herd 1 during the Stable School period. The y-axis shows the herd-level weekly probability of treatment distributed by parity and stage of lactation (days in milk (DIM)). 0-60 DIM is showed as a solid line, 61-280 DIM as a stippled line, > 280 DIM as a dotted line. The x-axis shows the period for the monitoring (by month). The weekly probability of treatment per parity and stage of lactation was calculated from the smoothened means of the parameter vector, which was calculated based on the historical (baseline estimation) and test data.

Figure 4 illustrates the daily development in herd-level milk yield for herd 1 during the Stable School period. The sum on the y-axis shows herd 1's daily deviation from the average herd lactation curve, which is estimated at the beginning of the Stable School period (March 2020). Uncertainties in the daily estimation of the summed parameters A and X were used to calculate the 95% confidence intervals. From the beginning of the Stable School period and until September 2020, cows in parity 2 and 3+ in particular yielded a statistically significant amount more than the herd average for these parities (up to 250 kg ECM more). In October 2020 and February 2021, all three parities yielded a statistically significant amount less than the herd average (approximately 100-150 kg ECM lower). Cows in parity 1 had fewer fluctuations in milk yield compared to parity 2 and 3+ cows. In August 2020, when the intervention (teat sealers) was initiated and until the effect on milk yield was expected to be detectable approximately 2 months later (after the dry period ended), the milk yield for all three parities fluctuated but had a decreasing trend of 100-200 kg ECM. This coincided with the initiation of the second "intervention" (shifting to AMS) in October 2020.

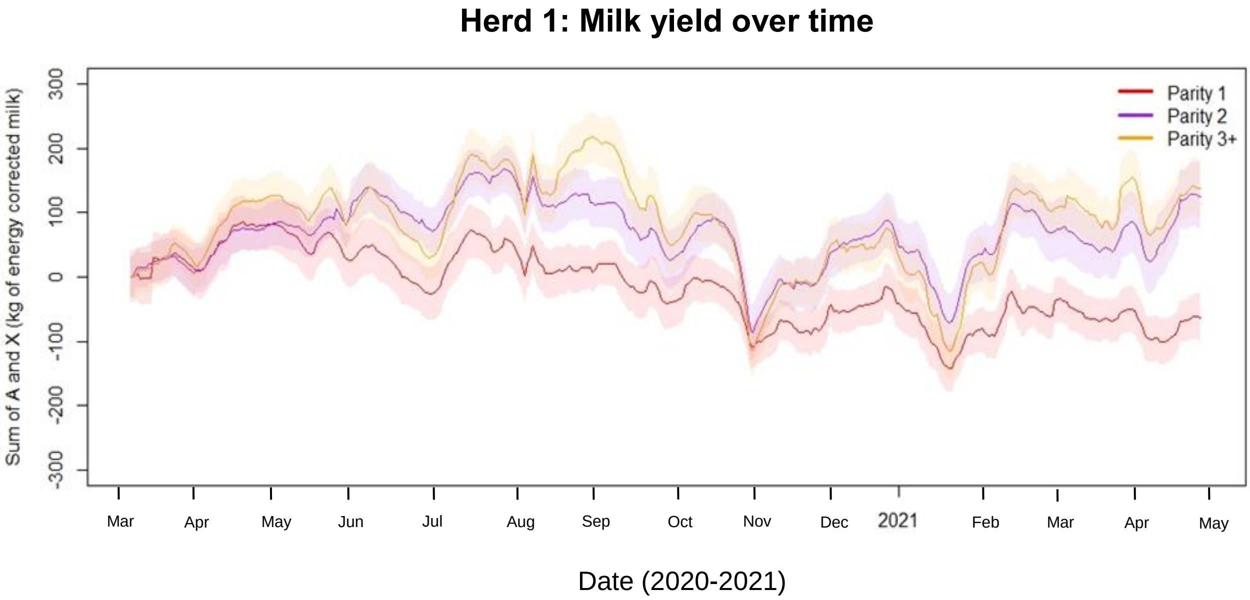

Figure 4. Dynamic linear model monitoring milk yield in herd 1. The y-axis shows the day-to-day sum (kg energy corrected milk) of the estimated parameters, A and X, and 95% confidence intervals per parity over time relative to herd average for herd 1 during the Stable School period (x-axis). The herd average sum for each parity is calculated based on the historical data at the beginning of the monitoring period (March 2020) and set to zero. Parameter X is a temporary random week effect that evolves over time according to the system equation, and A is the production potential in kg energy-corrected milk of a specific cow in a specific herd. A and X were calculated based on the historical (baseline estimation) and test data as the period proceeded.

Intervention effect on udder treatment risk and milk yield associated with teat sealer application and shifting to robotic milking

For herd 1, two different interventions, i.e. application of teat sealers and shifting to AMS, were modeled and their effects on udder treatment risk and milk yield were statistically tested. The two interventions will be illustrated with each their figures in Figure 5.A and B (udder treatment risk) and Figure 6.A and B (milk production).

The intervention parameter (on the logit scale) on udder treatment risk and confidence intervals (±1 standard deviation (SD) as dotted lines) for herd 1 associated with the implementation of teat sealers was plotted in Figure 5.A. The first stippled line marks the intervention start, i.e. application of teat sealers, in August 1, 2020. An eight-week adjustment period was applied to the model, meaning that the intervention effect was fully applicable from October 1, 2020. According to Figure 5.A, applying teat sealers had no statistically significant (at the 5% level) effect on treatment risk for udder diseases after October 1, 2020 and for the rest of the four-month evaluation period. The initiation of AMS in October 1, 2020, as illustrated in Figure 5.B and by the second stippled line, neither had a statistically significant effect on treatment risk for udder diseases.

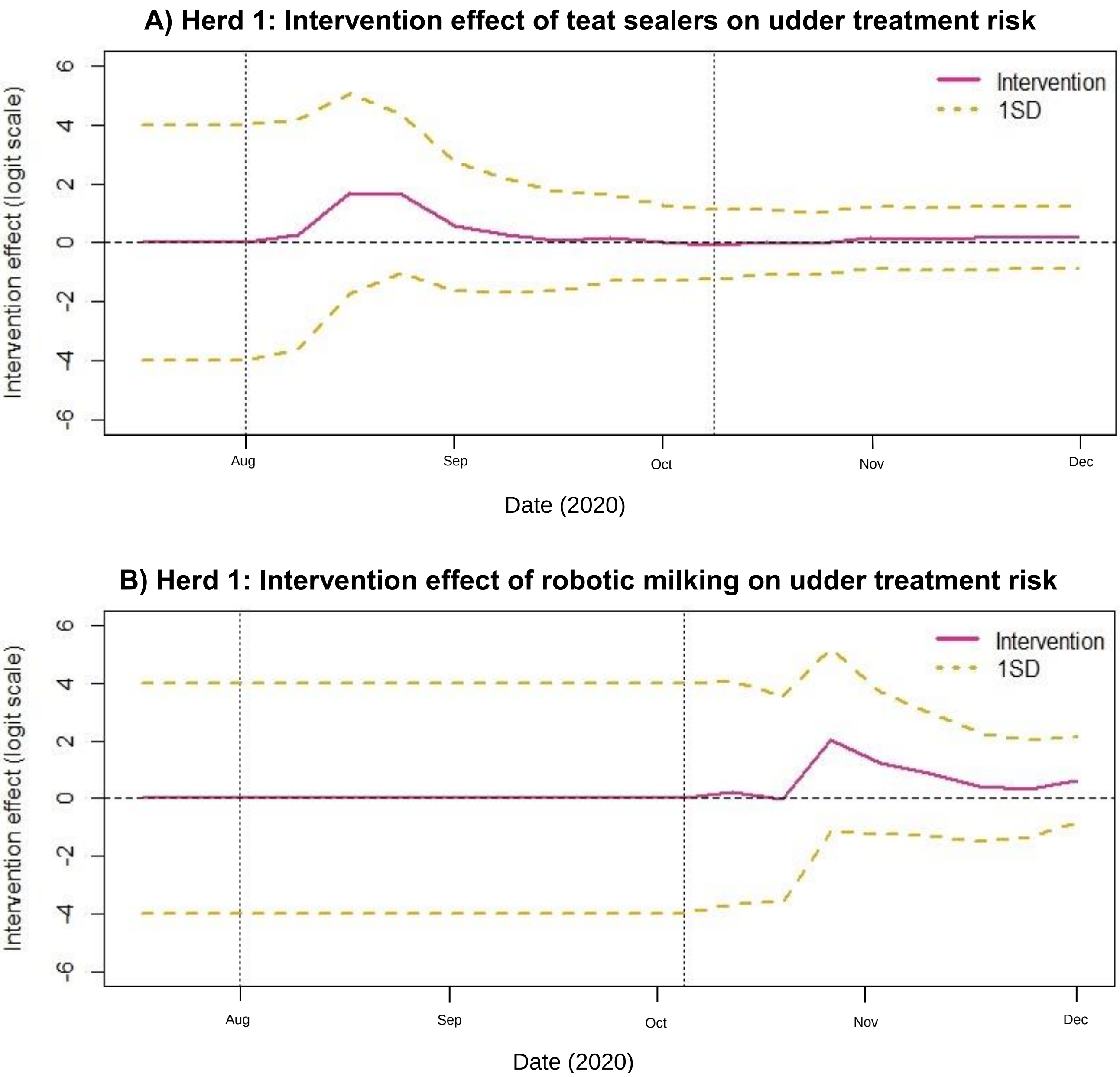

Figure 5. A) The y-axis shows the intervention effect together with confidence intervals (± 1 standard deviation (SD) as dotted lines) on udder treatment risk in herd 1 associated with the implementation of teat sealers in August 1, 2020 and forward (time on x-axis). The intervention effect on udder treatment risk is shown on the logit scale and can be changed to the probabilistic scale using $p_{nst} = (\exp(-\theta_{ns}) + 1)^{-1}$. Eight weeks adjustment applied, meaning that the intervention effect is gradually applied until eight weeks past August 1, 2020, where it is fully applied (October 1, 2020). The first vertical stippled line shows this intervention, and the second show the implementation time of robotic milking. **B)** The y-axis shows the intervention effect on udder treatment risk associated with the implementation of robotic milking in October 1, 2020 and forward (time on x-axis) in the same herd. Adjustments and stippled lines reflect the same as in Figure 5.A.

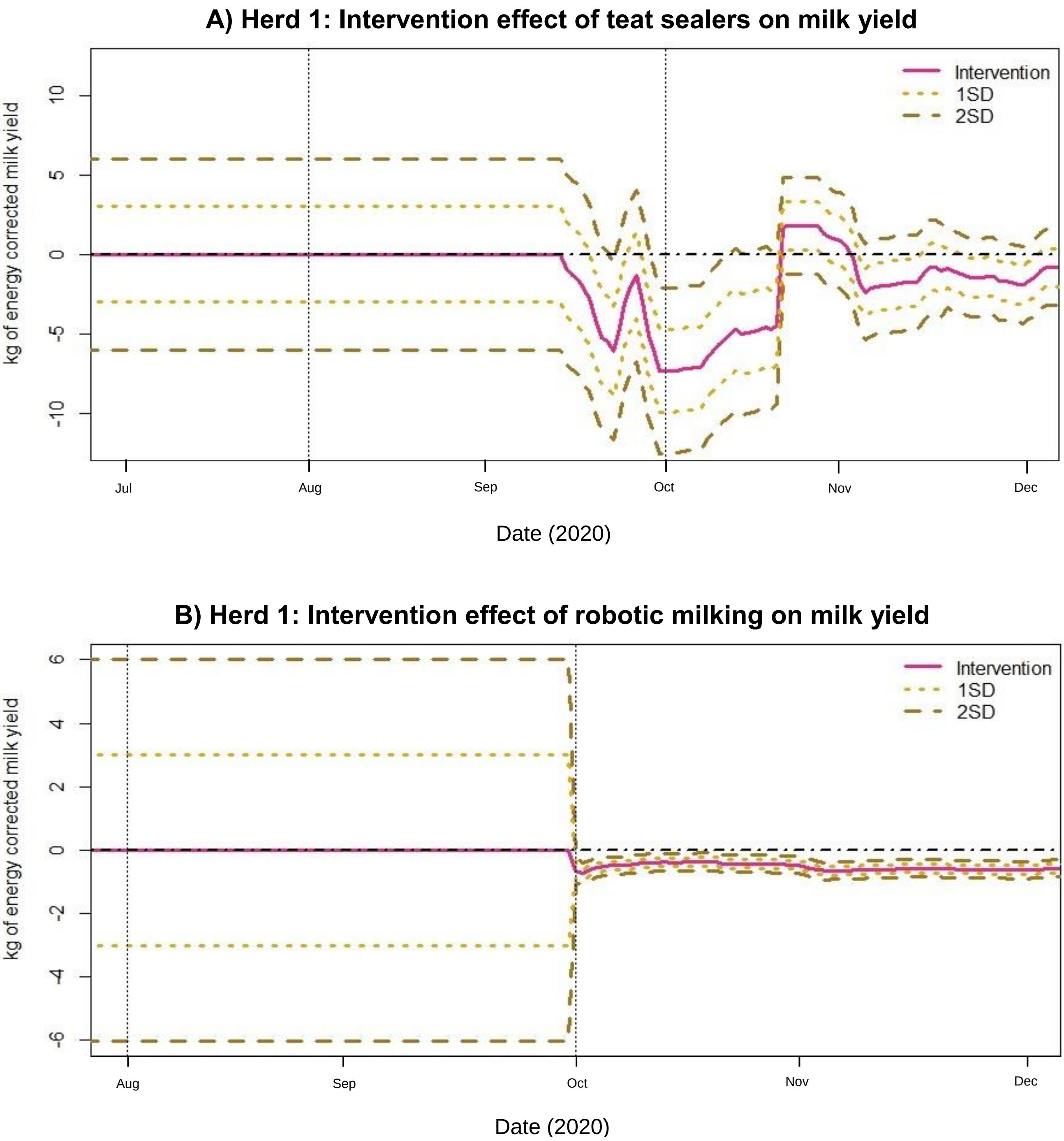

Figure 6. A) The y-axis shows the intervention effect (in kg energy-corrected milk per cow per day) together with confidence intervals (± 1 standard deviation (SD) as dotted lines, ± 2 SD as dashed lines) on milk yield in herd 1 associated with the implementation of teat sealers in August 1, 2020 and forward (time on x-axis). The intervention effect was applied gradually, i.e. for cows that had had a complete dry period after the start of the intervention, as reflected in the wider confidence intervals. The first vertical stippled line shows this intervention, and the second show the implementation time of robotic milking. **B)** The y-axis shows the intervention effect on milk yield associated with the implementation of robotic milking in October 1, 2020 and forward (time on x-axis) in the same herd. The intervention effect is applied immediately on October 1, 2020. The stippled lines reflect the same as in Figure 6.A.

Figure 6.A shows the intervention effect (kg ECM per cow per day) on milk production and confidence intervals (±1 SD as dotted lines, ±2 SD as dashed lines) for herd 1 associated with application of teat sealers in August 1, 2020 (first stippled line in both Figure 6.A and B). Figure 6.B shows the intervention effect (kg ECM per cow per day) on milk production and confidence intervals (±1 SD as dotted lines, ±2 SD as dashed lines) for herd 1 associated with the initiation of robotic milking in October 1, 2020 (second stippled line in both Figure 6.A and B). According to Figure 6.A, the application of teat sealers in herd 1 had a statistically significant (at the 5% level) negative effect on cow milk production after initiation of the intervention, i.e. a decreased milk production of approximately 6 [95%CI:-0.5;-11] kg ECM per cow per day in mid-September. Shortly after, simultaneously with the initiation of AMS in October 1, 2020, we observed a decrease in production of 7 [95%CI:-2.5;-12] kg ECM per cow per day. From November 1, 2020 and onwards, there appeared to be no statistically significant effect on cow milk production after application of teat sealers. The initiation of AMS also had a statistically significant negative effect on cow milk production after initiation, i.e. a decreased milk production of up to 1 [95%CI:-0.25;-1] kg ECM per cow per day, as seen in Figure 6.B.

Herd 2

Monitoring treatment risk and milk yield

Figure 7 illustrates the development in herd-level treatment risk for herd 2 during the Stable School period. The probability of treatment fluctuated during the period, i.e. it started at 1-6%, peaked at 2-10% in August/September 2020, and ended at a slightly lower level in May 2021 (1-4% probability of treatment). During November and December 2020, when the investigated intervention (adjustment of cubicles) was running, the probability of treatment fluctuated between 1-4% and 1-6%.

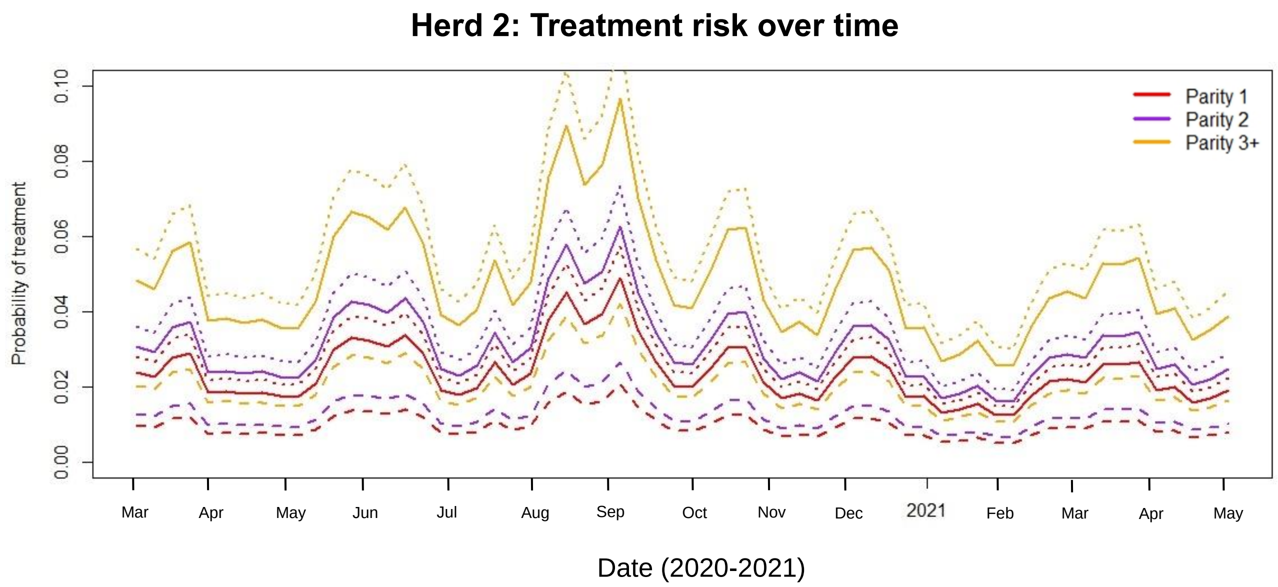

Figure 7. Dynamic generalized linear model monitoring treatment risk in herd 2 during the Stable School period. The y-axis shows the herd-level weekly probability of treatment distributed by parity and stage of

lactation (days in milk (DIM)). 0-60 DIM is showed as a solid line, 61-280 DIM as a stippled line, > 280 DIM as a dotted line. The x-axis shows the period for the monitoring (by month). The weekly probability of treatment per parity and stage of lactation was calculated from the smoothened means of the parameter vector, which was calculated based on the historical (baseline estimation) and test data.

The daily deviation in kg ECM from the average herd lactation curve (estimated in March 2020, at the beginning of the monitoring period) for each parity in herd 2 during the Stable School period is illustrated in Figure 8. At the beginning of the Stable School period, all three parities yielded a statistically significant amount more than the average herd yield for each parity (approximately 200 kg ECM). In August 2020, all three parities yielded a statistically significant amount less than the average herd yield for all parities (300-750 kg ECM less). The herd-level milk yield was at approximately the same level at the beginning and end of the period. In November and December 2020, the investigated intervention (adjustment of cubicles) was initiated and increasing milk yield levels were seen for parities 2 and 3+ over the following period (in the parity groups for which cubicles had been adjusted).

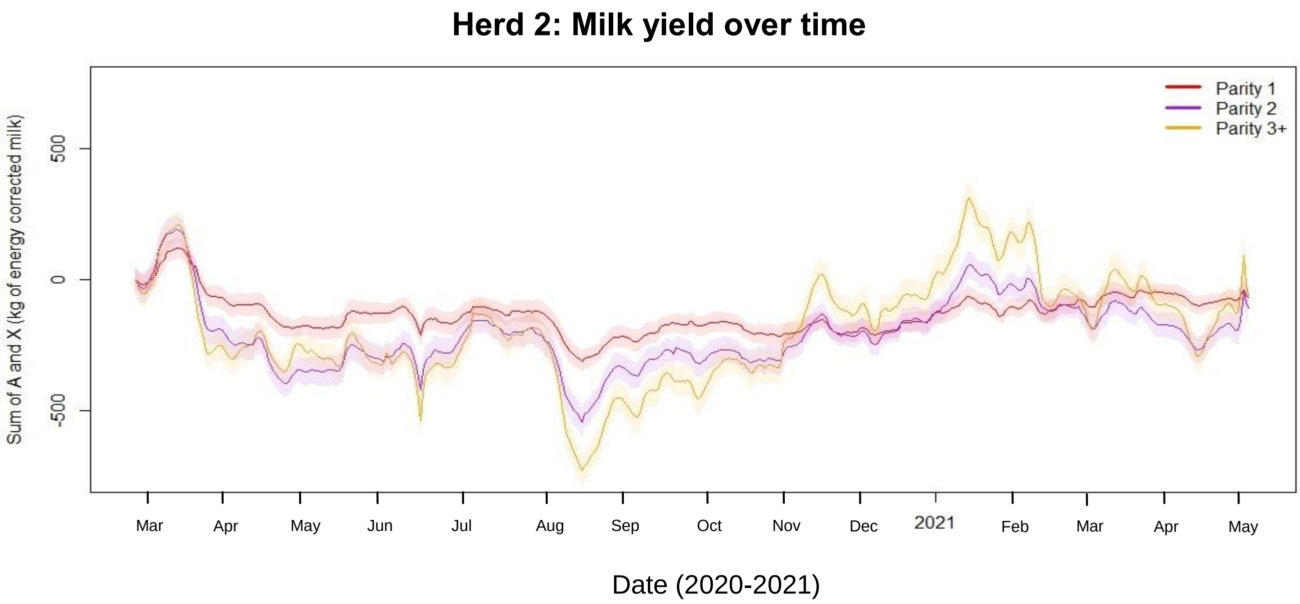

Figure 8. Dynamic linear model monitoring milk yield in herd 2. The y-axis shows the day-to-day sum (kg energy corrected milk) of the estimated parameters, A and X, and 95% confidence intervals per parity over time relative to herd average for herd 2 during the Stable School period (x-axis). The herd average sum for each parity is calculated based on the historical data at the beginning of the monitoring period (March 2020) and set to zero. Parameter X is a temporary random week effect that evolves over time according to the system equation, and A is the production potential in kg energy-corrected milk of a specific cow in a specific herd. A and X were calculated based on the historical (baseline estimation) and test data as the period proceeded.

Intervention effect on treatment risk and milk yield associated with adjustment of cubicles
For herd 2, adjustment of cubicles was the only intervention modeled. The milk yield and treatment risk models were adjusted to look only at the intervention effect for cows in parity 2 or above, since the cubicles were only adjusted in sections that housed cows in these parities.

The intervention parameter (on the logit scale) for treatment risk and confidence intervals (±1 SD as dotted lines) for herd 2 is plotted in Figure 9. The intervention time is November 1, 2020 (stippled line), the approximate day when adjustments of cubicles began. A four-week adjustment was applied to the model, meaning that the intervention effect was gradually applied until December 1, 2020. According to Figure 9, adjusting the cubicles had no statistically significant (at the 5% level) effect on treatment risk among cows in parity 2 and above at any time point after initiating the intervention.

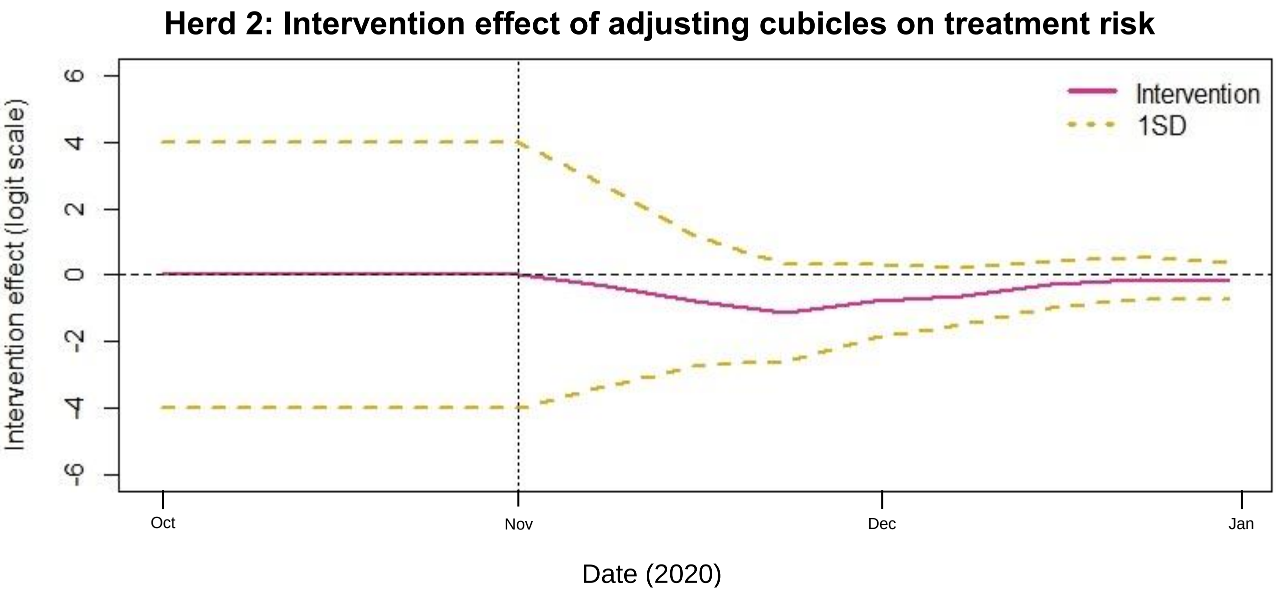

Figure 9. The y-axis shows the intervention effect together with confidence intervals (± 1 standard deviation (SD) as dotted lines) on treatment risk for cows in parity 2 and above in herd 2 associated with adjustment of cubicles in November 1, 2020 and forward (time on x-axis). The intervention effect on udder treatment risk is shown on the logit scale and can be changed to the probabilistic scale using $p_{nst} = (\exp(-\theta_{ns}) + 1)^{-1}$. The intervention effect is gradually applied over a four weeks period, meaning that the intervention effect is fully applied in December 1, 2020. The stippled line indicates the start of the intervention in November 1, 2020.

The intervention effect (kg ECM per cow per day) on milk yield and confidence intervals (±1 SD as dotted lines, ±2 SD as dashed lines) associated with adjustment of cubicles for herd 2 is plotted in Figure 10. According to this figure, the adjustment of cubicles in herd 2 had a short period with a statistically significant (at the 5% level) negative effect on milk production for cows in parity 2 and above of approximately 0.5 [95%CI:-0.1;-1] kg ECM per cow per day. However, for the rest of the evaluation period, no statistically significant effect on milk production was observed.

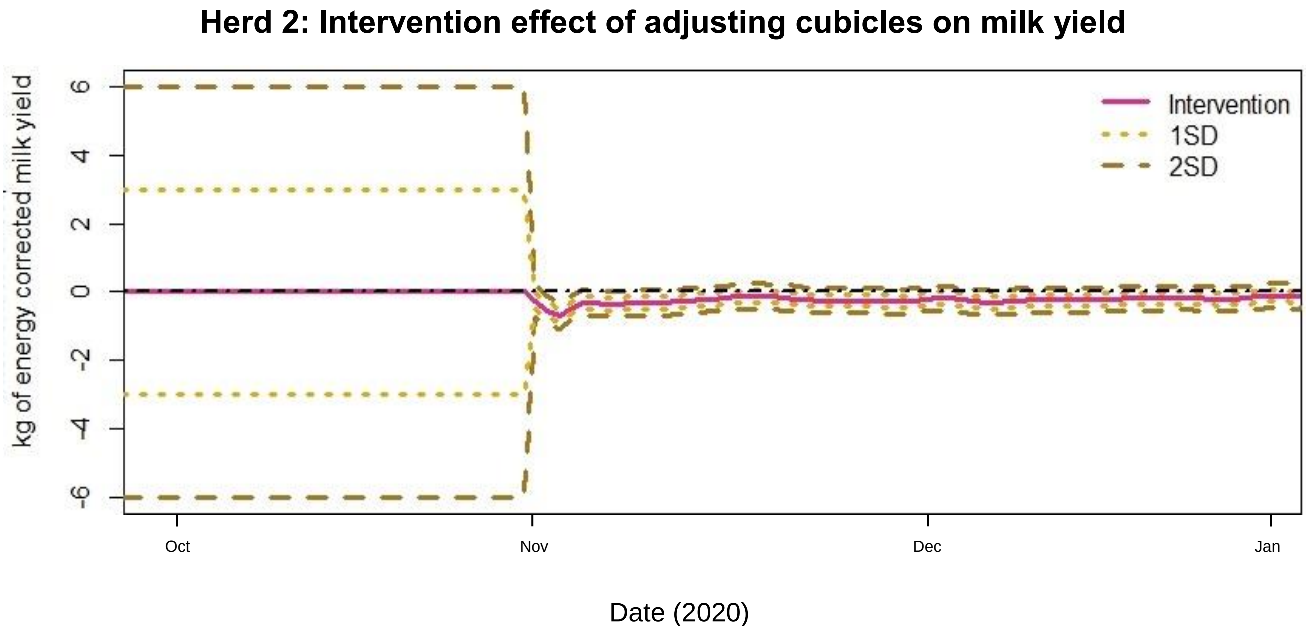

Figure 10. The y-axis shows the intervention effect together with confidence intervals (± 1 standard deviation (SD) as dotted lines, ± 2 SD as dashed lines) on milk yield (in kg energy-corrected milk per cow per day) for cows in parity 2 and above in herd 2 associated with adjustment of cubicles in November 1, 2020 and forward (time on x-axis). The intervention effect is immediately applied.

Discussion

Interpretation of results in herd 1

In summary, the results showed that the application of teat sealers in herd 1 had no statistically significant effect on treatment risk for udder diseases, but had a statistically significant negative effect on milk yield of approximately 6 [95%CI: -0.5;-11] kg ECM per cow per day around October 1, 2020. This effect was observed almost at the same time as the second "intervention" (shifting to AMS) was initiated in herd 1. The gradual implementation (as the cows calved) of the teat sealer-intervention resulted in fewer cows in the "test group", and therefore wider confidence intervals and less precise estimates of the intervention effect on milk production. The two concurrent interventions in herd 1 complicated the interpretation of results. The potential effect of changing to robotic milking could be seen in the monitoring graphs (Figure 3 and Figure 4) as the herd-level treatment risk and milk yield decreased during the following period (October to February). The monitoring graphs therefore supported the suggestion that the initiation of robots shortly after teat sealers were introduced might have masked any effects seen from the teat sealer-intervention.

Despite supposedly controlling for this by modelling both interventions, we found it difficult to differentiate whether this decrease in milk yield was mainly associated with the teat sealer application or the initiation of robots. The interpretation was complicated by the fact that the intervention effect associated with teat sealer application was not applied until shortly before the initiation of AMS. Therefore, whether the application of teat sealers or the transformation to robotic milking caused the decrease in milk production remains undecided.

Reflecting on the rather large decrease in milk production (approximately -6 kg ECM per cow per day), it seemed unlikely that teat sealers alone could have caused such a reduction, even though high levels of hygiene are required for successful application of teat sealers. For example, the farm personnel might involuntarily have introduced bacteria to the udder if application procedures were not strictly hygienic, thereby counteracting the effect of teat sealers by creating a sealed environment for udder infections (Crispie et al., 2004). This would subsequently have led to an increase in udder treatments and most likely a decrease in milk production among diseased cows, attributing to the decreased milk production and limited effect on probability of treatment seen in Figure 5 and Figure 6. However, we hypothesize that this cannot explain a decrease in milk production of approximately 6 kg ECM per cow per day. This intervention effect on milk production associated with teat sealer application was only valid for cows that had just calved (according to the criteria applied for the intervention effect), i.e. a group of cows that would be extra susceptible towards the transformation to AMS right after their calving. As such, this was an additional argument that the intervention effect of application of teat sealers was still masked by the change to robotic milking.

The intervention example from herd 1 illustrates the complex issue of effect estimation under field conditions, and we argue that this would be no matter the statistical methods used. In general, it is best to avoid estimating the effect of an intervention during periods with concurrent ongoing interventions because it leads to issues of causality in terms of the association between changes seen in milk yield and/or treatment risk and the investigated interventions (i.e. if the application of teat sealers did indeed cause a decrease in milk production). We argue that the SSMs for effect estimation nor simpler statistical analysis are able to solve these issues. To better understand the true effect of teat sealer application in this herd, the intervention could be halted and repeated during a period with fewer changes. Alternatively, another approach to observational design of data collection and analysis could be taken; e.g. a pragmatic trial design involving randomly allocated cows or all cows in different periods (on/off) during a quieter season on the farm, including strict and refined application procedures (Lastein, 2012).

Furthermore, an alternative and more appropriate health and production outcome than milk yield in relation to the application of teat sealers could have been applied. For example, SCC may have been a more biologically plausible choice. However, due to time limitations during this study, it was not possible to develop a SCC model.

Interpretation of results in herd 2

In relation to the adjustment of cubicles-intervention in herd 2, an initial short period with a statistically significant decrease in milk production was observed, however, for the rest of the period, no statistically significant changes in cow treatment risk or milk production were observed. The initial statistically significant decrease in milk production could be due to disturbance by the farm personal adjusting the cubicles. Even though they continued doing so throughout November 2020, their first entry to the barn sections might have caused greater disturbances among the cows. The monitoring graphs for herd 2 (Figure 7 and Figure 8) revealed drastic changes in levels during a period before the adjustment of cubicles was initiated, i.e. the herd-level milk yield decreased and treatment risk increased in August/September 2020. Therefore, ongoing effects from changes in August/September could have masked the effect of adjusting the cubicles during November 2020. However, the milk yield and treatment risk levels appeared to have "normalized" before November 2020, and we therefore argue that masking was unlikely. Furthermore, no other specific interventions (e.g. feed shifts) were identified and described during the study period that could have explicitly caused these changes, meaning that modelling of multiple interventions was not obvious, as we otherwise demonstrated is possible in herd 1 (shift to robotic milking and teat sealer).

Reasons for the limited effect of adjusting the cubicles could be due to the expected gradual onset of effect (due to time constraints among farm personnel) and the chosen evaluation period of two months (November to January). According to a study by Bernardi et al. (2009), improvement in gait scores from adjusting the neck rail position was observed after a five-week period. Therefore, we might have seen some effect of the adjustment of cubicles within the two-month evaluation period, but we might not have seen it all. The issue of the expected onset of an intervention illustrates another challenge of effect estimation and determining causality under real-life herd conditions: interventions should be planned and executed within a relatively short period to be proper candidates for effect estimation. We argue that this issue is valid no matter the chosen statistical method for effect estimation.

The fact that we seemingly observed a limited effect from adjusting the cubicles could be perceived as a positive result for the personnel in herd 2, as adjusting the cubicles did not seem to result in impaired herd health. In contrast, the adjustment could also be perceived as futile; a more pronounced effect may be desired after an investment of so many working hours. However, as stated in the Materials and methods section, very different effects on cow treatment risk could be seen from this intervention based on the referred literature, i.e. a decreased treatment risk due to fewer locomotive disorders or an increased treatment risk due to more mastitis cases. Therefore, treatment risk could be considered for different individual diseases (e.g. locomotive disorders versus udder diseases) before a final decision is made about whether or not to continue the adjustment of cubicles in other barn sections. However, SSMs would require a relatively large number of observations in each treatment category to provide precise estimates of the intervention effect. This could be a challenge in some herds.

Application and perspectives

This is the first study to use SSMs to estimate the effect of interventions on multiple outcomes under field conditions. Another study has investigated the potential of DLMs for estimating the effect of an intervention on milk yield, though with different interventions tested in the study herds and under more controlled herd conditions (Stygar et al., 2017). For herd 2 in particular, there was no exact onset of intervention as the farm personnel had to adjust the cubicles when time allowed. Therefore, in practice, the cubicles were adjusted over a one-month period. This will naturally delay any effect seen from the intervention and confound the applicability of the SSMs in terms of setting the right conditions for e.g. intervention timing. Furthermore, herd 1 had multiple ongoing interventions; the concurrent introduction of milking robots in particular added a non-standard aspect to the production process. Stygar et al. highlighted that a standard production process in the study herd was an important prerequisite for a well-functioning DLM (2017). Therefore, simultaneous actions at each herd might mask or override any potential effect seen from the investigated intervention, which is why interventions in general should be implemented and tested during "calm" periods. Furthermore, the intervention onset should be easy to determine. However, we argue that these issues of determining the strong timely association (e.g. as a proxy for causal relationship) between intervention and effect would be valid also for other statistical tools for effect estimation. The causality issue comprise the core of field-based effect estimation challenges, which only can be more optimally solved through the use of controlled randomized herd trials. Such approaches, though, face challenges too, when applied under real-life herd conditions (Lastein, 2012).

SSMs comprise a useful tool for decision-making in a field-based dairy context, because they consider the distribution of parities and stages of lactation and the timing of the intervention. Thus, such models provide estimates for the effect of the intervention, while also informing about the uncertainties around those estimates. The results are non-generalizable to the overall farm population, but if applied in a local context, they comprise a useful and precise tool to facilitate decision-making for farmers and veterinarians. However, as already emphasized, it is important that the application of any statistical evaluation method take into account the nature of an intervention, e.g. the expected timing and outcome. Here follows that we would recommend that evaluation should be restricted to visual evaluation based on SSM monitoring graphs instead of effect estimation if the type of intervention in focus is expected to have a complicated effect pattern or if it is potentially masked by other ongoing changes. If SSMs are used in this way, only major changes in outcome will be visually detected and because the statistical testing procedure is not performed, it will not contribute to misinterpretation of the intervention effects.

A few improvements and other considerations of the developed SSMs in this paper are suggested to improve their application under field conditions.

The SSMs presented in this paper could be applied in two different ways: to test the effect of a specific intervention on chosen outcomes prospectively or to monitor the levels of these outcomes retrospectively. Ideally, the conditions of the models should differ depending on the application. The assumption in both SSMs that the herd-specific parameters were constant is particularly difficult to justify when monitoring over longer periods. In those cases, the herd-specific parameters should evolve over time. This can be achieved by applying the expectation-maximization algorithm used in Bono et al. (2012) for estimation of the variance components associated with the evolution of the herd level. Another approach would be to manually re-estimate the parameters at regular intervals, e.g. when entering a monitoring period when interventions are planned but the direction of the effect of these interventions is unknown.

In addition to allowing the herd-specific parameters to evolve over time, both models should be expanded to include seasonal effects directly. Currently, both models handle seasonal fluctuations in an indirect manner, i.e. a high-yielding cow one day is also expected to be a high-yielding cow the day after, and a high herd-level treatment risk one week is also expected to be high the following week. However, neither the milk yield model nor the treatment risk model are able to learn from seasonal patterns, e.g. recurring high yields or treatment risks during specific months or quarter of the year. This would be a valuable add-on as seasonal patterns in cattle milk production (Wood, 1970) and treatment risk (Markusfeld, 1984; Bruun et al., 2002; Olde Riekerink et al., 2007) have been established and could thus be expected.

In the monitoring graph for treatment risk in herd 1 (Figure 3), no parity-specific patterns could be seen, due to the conditions applied for the DGLM (constant effects assumed for parity and stage of lactation). In future model applications, different effects between parities, lactation stages and their interaction effects should be allowed so that different effects within e.g. different parities can be detected. This extension of the DGLM could be investigated further to determine whether the application of teat sealers was a disadvantage only for certain parity groups. For example, parity 3+ cows might experience poor udder health (e.g. a higher SCC) compared to other parity groups, and a larger proportion of parity 3+ cows might have teat sealers applied in combination with antimicrobials, meaning that the level of hygiene at application would have less impact.

The SSMs in this paper evaluated responses in herd-level milk yield and treatment risk after the initiation of an intervention. These outcomes were chosen because the overall goal of the Stable School was “improved health – fewer antimicrobials”, and evaluation of treatment risk as a proxy for AMU, and milk yield as a proxy for herd health and production seemed relevant. However, it would also be highly relevant to evaluate other outcomes in order to obtain a holistic picture from a herd health and production perspective, e.g. SCC as a better proxy for herd health, especially in relation to the teat sealer intervention in herd 1. In general, evaluated outcomes should be fitted to the intervention investigated to support farmer-veterinarian decision making in the best way possible.

In general, the purpose of applying a SSM should be considered when choosing the application form. If the purpose is to proactively test a known and well-defined intervention that is planned during a “calm” period and is expected to influence a certain outcome (e.g., milk yield or treatment risk), a SSM with constant herd-specific parameters for effect estimation should be used. Conclusions on the exact effect of the intervention can be drawn when the intervention period has ended, or when the full effect of the intervention is expected to have been seen. If the purpose is to test a known and well-defined intervention where the effect is uncertain, a SSM with constant herd-specific parameters for monitoring should be used. In that case, the herd should be monitored closely as the intervention proceeds, and conclusions can be drawn when the intervention period has ended. The monitoring tool offers no specific effect estimation, but specific periods with known interventions can be investigated retrospectively using the effect estimation extension. Finally, if the purpose is to monitor a herd without knowledge of any specific interventions, the least “rigid” form of a SSM should be applied, i.e. with evolving herd-specific parameters for monitoring. This monitoring can in principle continue for an indefinite time, and evaluations can be done regularly but retrospectively. As with the other application of the monitoring extension, no direct effect estimation of any applied interventions can be made.

A potential drawback of the application of the SSMs in this study was the availability of data, i.e. the use of test day information in combination with records of herd bulk tank milk, instead of daily AMS data. Stygar et al. (2017) highlighted the lack of sufficient production data as a limiting factor for the DLM developed in their study, as sufficient data are necessary to obtain precise estimates for the intervention parameters. In this study, we accounted for this drawback by predefining ρ and removing the correlation structure in the estimation of the milk yield parameters. This adjustment resulted in less precise parameters with wider confidence intervals. However, for real-life decision-making purposes during advisory processes, i.e. for an indication of whether or not an intervention is beneficial (as illustrated in this study and the study by Stygar et al. (2017)), we argue that the adjusted DLM is justified and useful. Furthermore, since only 22.2% of Danish cows are milked using AMS, thus having data available on a daily basis (Farre and Budde, 2021), the use of herd bulk tank milk recordings are more referable to a real-life Danish advisory setting. Therefore, depending on the type of measured outcome and the production data available, results should be interpreted with this precision-related compromise in mind.

The developed DLM can only be used for herds with consistently registered dry periods. This is because the number of lactating cows per day contributing to the herd bulk tank milk will otherwise be wrongly estimated. Missing registrations of dry periods can be due to an oversight on the part of the farmer or due to abortions, i.e., cows giving birth before entering the dry period. Missing registrations due to abortions will most likely be secondary and infrequent in most herds, whereas farmers forgetting to register dry-off dates occurs more regularly. Knowledge of data consistency and availability is therefore important before these SSMs are applied in a specific herd.

Conclusion

This study outlined perspectives of application of two multivariate SSMs to monitor and estimate the effect of an intervention on treatment risk and milk yield in dairy herds under field conditions. SSMs have methodological advantages over simpler statistical analytical tools because they take into account herd dynamics and autocorrelation as well as calibrates to herd conditions. However, in a real-life farm setting, where the effect of implemented interventions is under investigation, effect estimation in general face challenges in terms of determining causal relationships. This was illustrated by the interventions investigated in this study: they had a non-specific onset, were initiated during unsettled times, and had varying coherence with the measured outcomes, thus confounding the applicability of the SSM effect estimation tool. The monitoring graphs were useful for providing a retrospective overview of the production and health flow in a herd and as an alternative to effect estimation. Therefore, future application of SSMs to assist decision-making by veterinarians and farmers during real-time advisory processes should be planned according to the purpose of the application as well as the nature of the intervention of interest and the expected outcome. Finally, effect estimation of interventions using any statistical method should only be applied during stable herd conditions.

Conflicts of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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10 Appendix

Appendix 1: Interview study

Informed consent signed by interviewed Danish veterinarians and farmers (translated from Danish to English).

UNIVERSITY OF COPENHAGEN
DEPARTMENT OF VETERINARY AND ANIMAL SCIENCES

Name:
Address:
Phone number:

Informed consent

I, ________________________________, would like to participate in an interview study conducted in relation to a research project conducted at University of Copenhagen.

The research project aims at investigating attitudes among farmers and veterinarians on antimicrobial use in Danish dairy herds. Furthermore, it investigates the motivation for reduction of use and how and if different actions within a herd health consultancy setting may influence the herd production and antimicrobial use.

By agreeing to participation, you are ensured complete confidentiality. I, as a participant, give my consent that the interview may be audio recorded and used for analysis in relation to the research project. The consent can at all times be retracted as long as it is done before the data analysis is initiated.

SECTION FOR PRODUCTION, NUTRITION AND HEALTH

GRØNNEGÅRDSVEJ 2, 1870 FREDERIKSBERG, DENMARK

DIR *ANONYMISED*

Email address anynomised

REF: NKS

Date:

Signature: ________________________________

Kind regards,

Nanna Krogh Skjølstrup
PhD Student, veterinarian

The research project has been evaluated by the Research Ethics Committee for Science and Health, University of Copenhagen. The data will be handled with approval from the Danish Data Protection Agency.

Information scheme on data handling given to interviewed farmers and veterinarians (translated from Danish to English).

Information on handling of personal data in research project at University of Copenhagen

Title of the research project	Attitudes and practices in relation to antimicrobial use among Danish dairy farmers and cattle veterinarians
What is the project about and why do we collect personal data?	The research project aims at investigating the attitudes and practices in relation to antimicrobial use among Danish dairy farmers and cattle veterinarians. This will be investigated through individual interviews. The findings will be used in a thesis and scientific articles in relation to the thesis. There are identified no risks related to participation in the research project.
What personal data does the project process?	The project processes the following information about the participants: ✓ Name ✓ Age ✓ Gender
For how long is personal data stored?	Your data will be stored at the University of Copenhagen in personally identifiable form until April 1, 2025. After this date, your personal data will be anonymised or deleted.
Will personal data be passed on to others, such as researchers at other universities?	✓ Your data collected for the project will not be passed on to others.
Personal data is obtained from:	✓ We have only obtained data from you
We are permitted to process your data in accordance with the rules in the General Data Protection Regulation (GDPR). We must inform you of the rules that apply to our work with your data.	✓ Article 6 (1) (a), which gives the University of Copenhagen the right to process non-sensitive personal data about you on the basis of your consent.
The participants' rights under General Data Protection Regulation (GDPR)	As a participant in a research project, you have a number of rights under GDPR. Your rights are specified in the University of Copenhagen privacy policy: https://informationssikkerhed.ku.dk/english/protection-of-information-privacy/privacy-policy/
Person responsible for storing and processing of personal data	University of Copenhagen, CVR no. XXXX is the data controller responsible for processing personal data in the research project. The research project is headed by Nanna Krogh Skjølstrup, who can be contacted on XXXXX (address, telephone and e-mail)

Appendix 2: Stable School study

Informed consent signed by participating farmers and facilitating veterinarians of the Stable School (translated from Danish to English).

UNIVERSITY OF COPENHAGEN
DEPARTMENT OF VETERINARY AND ANIMAL SCIENCES

Name:
Address:
Phone number:
CHR number:

Informed consent

I, ______________________________, would like to participate in two interview studies conducted in relation to a research project at University of Copenhagen. One interview before the Stable School is imitated and another interview at the end.

The research project investigates the effect of Stable School participation on antimicrobial use in conventional dairy herds.
Participation is voluntary. Your name will not appear from the analysed interviews but full anonymity cannot be granted. The analysed interviews are used for scientific publications and the undersigned's thesis. Your personal data are handled according to the rules of the Danish Data Protection Agency.

I give my consent that the interview may be audio recorded and used for analysis in relation to the research project. Furthermore, I confirm to have read the information scheme. A consent can be retracted at any time by contacting the undersigned.

Date:
Signature: ______________________________

Kind regards,

Nanna Krogh Skjølstrup
PhD Student, veterinarian

The research project has been evaluated by the Research Ethics Committee for Science and Health, University of Copenhagen. The data will be handled with approval from the Danish Data Protection Agency.

SECTION FOR PRODUCTION, NUTRITION AND HEALTH

GRØNNEGÅRDSVEJ 2, 1870 FREDERIKSBERG, DENMARK

DIR ANONYMISED

Email anonymised

Information scheme on data handling given to participating farmers and facilitating veterinarians of the Stable School (translated from Danish to English).

Information on handling of personal data in research project at University of Copenhagen

Title of the research project	The effect of Stable School participation on antimicrobial use, health and production in conventional dairy herds.
What is the project about and why do we collect personal data?	The research project aims at investigating the effect of a Stable School on the use of antimicrobials among the participating farmers and the facilitating veterinarian in conventional dairy herds. This will be investigated through individual interviews with all participants and facilitators before and after the Stable School course. The findings will be used in a thesis and scientific articles in relation to the thesis. There are identified no risks related to participation in the research project.
What personal data does the project process?	The project processes the following information about the participants: ✓ Name ✓ Age ✓ Gender
For how long is personal data stored?	Your data will be stored at the University of Copenhagen in personally identifiable form until April 1, 2025. After this date, your personal data will be anonymised or deleted.
Will personal data be passed on to others, such as researchers at other universities?	✓ Your data collected for the project will not be passed on to others.
Personal data is obtained from:	✓ We have obtained data about you from: the statements given by you at the interviews and through the Danish Cattle Database.
We are permitted to process your data in accordance with the rules in the General Data Protection Regulation (GDPR). We must inform you of the rules that apply to our work with your data.	✓ Article 6 (1) (a), which gives the University of Copenhagen the right to process non-sensitive personal data about you on the basis of your consent.
The participants' rights under General Data Protection Regulation (GDPR)	As a participant in a research project, you have a number of rights under GDPR. Your rights are specified in the University of Copenhagen privacy policy: https://informationssikkerhed.ku.dk/english/protection-of-information-privacy/privacy-policy/
Person responsible for storing and processing of personal data	University of Copenhagen, CVR no. XXXX is the data controller responsible for processing personal data in the research project. The research project is headed by Nanna Krogh Skjølstrup, who can be contacted on XXXXX (address, telephone and e-mail)