DOCTOR OF PHILOSOPHY

Knowledge, attitudes and behaviour of local veterinary practitioners and dairy farmers to antimicrobial resistance (AMR) and their intention to change to more responsible antimicrobial use practices

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Knowledge, attitudes & behaviour of local veterinary practitioners and dairy farmers to antimicrobial resistance (AMR) and their intention to change to more responsible antimicrobial use practices

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Sarah Farrell

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Declaration

I declare that except where specific reference is made to the work of others, the contents of this dissertation are original and have not been submitted in whole or in part for consideration for any other degree or qualification in this, or any other University. This dissertation is my own work and contains nothing which is the outcome of work done in collaboration with others, except as specified within the acknowledgements of the appropriate chapters. The data collected during these projects were used to supplement the data collected by me for this thesis, and all data analysis were therefore carried out by myself.

Sarah Farrell

2023

Abstract

Antimicrobial Resistance (AMR) is a global health emergency, threatening disease treatment and control in both humans and animals. Agricultural Antimicrobial Use (AMU) has been linked to the emergence of resistant bacteria in humans and therefore is of increasing concern in the fight against AMR. Understanding attitudes and factors which influence the decision-making process of farmers and veterinarians to use antimicrobials, and the translation of behavioural intentions into sustained behaviour change is increasingly recognized as a key strategy for tackling AMR. Studies are needed to better understand the reasons behind AMU as there is a lack of research applying theoretical models to farmers and veterinarians AMU practices on dairy farms. Such work can help to propose behaviour change interventions which are more likely to bring about real change to AMU on farm.

Thus, using a mixed methods approach this thesis investigated the factors influencing the behaviours of dairy farmers and veterinarians on the Island of Ireland when deciding to use and prescribe antimicrobials (Dairy farmer surveys n=240, veterinarian surveys n=26, veterinarian interviews n=12). It uncovered the barriers and enablers to responsible AMU within the dairy sector and using COM-B model of behaviour change, proposed interventions which may be successfully implemented and sustained to promote responsible AMU on dairy farms.

Based on these findings, the Behaviour Change Wheel was used to propose potential behaviour change interventions to promote more responsible AMU behaviours for both dairy farmers and veterinarians. As a final step, a multi-stakeholder workshop comprised of dairy farmers, dairy farm advisors, dairy technologists and a veterinarian (n=10) took place. Key stakeholders from the Northern Irish dairy sector rated the proposed behaviour change interventions using the APEASE criteria for behaviour change interventions and took part in a facilitated discussion for each intervention. The involvement of relevant stakeholders in the co-development of interventions helps to maximise the success rate of behaviour change interventions. Farmer education programmes to improve awareness of their role in AMR, farmer peer information sharing groups for farmers to share experiences of reducing AMU successfully with their peers and encourage others to act and training to impart skills needed by farmers to reduce AMU while maintaining herd health and productivity were the top-rated interventions.

The use of the COM-B model has strengthened the understanding of the decision-making process undertaken by farmers and veterinarians when choosing to treat dairy cattle with antimicrobials. This understanding coupled with the further step of encompassing behaviour change theory to facilitate responsible AMU can help implement interventions which have a greater chance of resulting in positive change and more responsible AMU on dairy farms.

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Dedication

This thesis is dedicated to my mother Brenda for her unconditional love and support.

Publications and Presentations related to this thesis

Publications

Farrell, S., McKernan, C., Benson, T., Elliott, C., & Dean, M. (2021). Understanding farmers' and veterinarians' behavior in relation to antimicrobial use and resistance in dairy cattle: A systematic review. *Journal Of Dairy Science*, *104*(4), 4584-4603. doi: 10.3168/jds.2020-19614

Farrell, S., Benson, T., McKernan, C., Regan, A., Burrel, A., Dean, M. (2023). Factors influencing dairy farmers' antibiotic use: An application of the COM-B model. *Journal of Dairy Science, 106*(6), 4059-4071. doi: 10.3168/jds.2022-22263

Farrell, S., Benson, T., McKernan, C., Regan, A., Burrel, A., Dean, M. (2023). Exploring veterinarians' behavior relating to antibiotic use on dairy farms using the COM-B model of behaviour change. *Research in Veterinary Science, 156,* 45-53. doi: 10.1016/j.rvsc.2023.01.019

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Exploring veterinarians' behavior relating to antibiotic use on dairy farms using the COM-B model of behaviour change. SafeFood AMR in agriculture seminar. Dublin: September 2022 (Oral presentation)

Knowledge and attitudes of local dairy veterinary practitioners and farmers to antimicrobial resistance. IGFS PGR Seminars, Queen's University, Belfast: October 2022. (Oral presentation)

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List of abbreviations

AGPs – Antibiotic growth promoters

AMR – Antimicrobial Resistance

AMU – Antimicrobial Use

BCW – Behaviour Change Wheel

BDCT – Blanket Dry Cow Therapy

BPS - The British Psychological Society

BVA – British Veterinary Association

CPPR – Client Patient Practice Relationship

DAERA- Department of Agriculture, Environment and Rural Affairs

DCT – Dry Cow Therapy

HP-CIA – Highest Priority Critically Important Antibiotics

IGFS - Institute for Global Food Security

IMI - Intramammary infections

NI – Northern Ireland

RCVS – Royal College of Veterinary Surgeons

ROI – Republic of Ireland

RUMA - Responsible Use of Medicines in Agriculture Alliance

SDCT – Selective Dry Cow Therapy

TDF - Theoretical Domains Framework

UFU – Ulster Farmers Union

VMD – Veterinary Medicines Directorate

WHO – World Health Organisation

1. Chapter One: Introduction

1.1 Overview of objectives & research questions

To propose effective behaviour change interventions for the successful promotion of responsible antimicrobial use (AMU) on dairy farms, it is important that the perceptions of key stakeholders responsible for the prescription and use of antimicrobials are considered.

Therefore, this thesis aims to explore the knowledge, awareness, perceptions and current practices of dairy farmers and veterinarians in relation to antimicrobial resistance (AMR) and responsible AMU. Current behaviours will be investigated to identify factors influencing AMU and prescription on dairy farms and highlight current barriers faced by both farmers and veterinarians when aiming for responsible AMU. Application of the COM-B model to these findings will enable identification of behaviour change interventions to improve dairy farmer and veterinarians' capability, opportunity, and motivation to change their behaviour and adopt more responsible AMU practices. Key stakeholders from the dairy sector will assess the feasibility of these interventions resulting in the proposal of behaviour change interventions perceived as having the greatest potential to achieve more responsible AMU on dairy farms.

1.1.1 Aims & research questions

While there is some evidence to show the potential indicators of farmer and veterinarians' behaviour in relation to AMU on farms, it is not clear what dairy farmers and veterinarians' attitudes, and knowledge are in relation to AMR on the island of Ireland and what influences their efforts to use antimicrobials responsibly. Therefore, the aim of this research was to investigate the knowledge and attitudes dairy farmers and veterinarians in Ireland have towards prudent AMU and AMR, to evaluate current practices and highlight barriers and pressures associated with achieving prudent AMU in NI dairy farming. The research will identify predictors of AMU in NI dairy farming, to identify evidence-based solutions, to promote behaviour change and encourage alternative animal health management strategies, reducing the need for AMU.

The following objectives have been specified to achieve the aims of this project:

(1) Investigate the knowledge of and attitudes towards responsible AMU and AMR of both dairy farmers and veterinarians.

(2) Evaluate current practices and identify factors influencing responsible AMU on dairy farms for dairy farmers and veterinarians.

(3) Assess the feasibility of potential behaviour change interventions to overcome barriers to responsible AMU on dairy farms from the perception of key dairy sector stakeholders.

(4) Propose behaviour change interventions to overcome current barriers experienced by dairy farmers and veterinarians to promote more responsible AMU on dairy farms.

1.2 Thesis contributions

Achievement of the research objectives stated above, has resulted in this thesis making a number of policy and methodological contributions, which are outlined below:

Contribution 1: This research provides further evidence of the factors influencing responsible AMU by dairy farmers and veterinarians.

Contribution 2: The research adds to existing literature in the area of farmer AMU practices, the use of statistical regression enables the prediction of farmers stopping blanket use of antimicrobials.

Contribution 3: Unlike previous research, this research applied behaviour change theory (COM-B model) to findings from dairy farmer and veterinarian studies to further understand their current behaviour and identified strategies to promote behaviour change.

Contribution 4: This research gained stakeholder feedback on behaviour change interventions recommended based on quantitative and qualitative findings, enabling identification of interventions which are perceived as most feasible and likely to succeed in real world applications.

Contribution 5: This research proposed behaviour change interventions which can guide policy makers to promote more responsible AMU on dairy farms successfully.

1.3 Thesis structure

This thesis is organised into eight chapters.

Chapter 1 sets out the objectives and justification of this research, ethical approval and fundings details are also explained in this chapter.

Chapter 2 provides background information on AMR, AMU in agriculture and the importance of responsible AMU in dairy farming as an AMR stewardship strategy. This chapter also provides information on the importance of applying behaviour change theory to findings in orders to promote sustained behaviour change and specifically introduces the COM-B model of behaviour change which was utilised for studies 1 and 2 of this thesis.

Chapter 3 presents a review of the literature relating to farmer and veterinarians' perceptions relating to AMR and AMU on dairy farms. This chapter focuses on collating and synthesising all

available published data relating to dairy farmer and veterinarians' knowledge, attitudes, and perceptions of AMR and responsible AMU. This chapter details the gaps in knowledge regarding how these two stakeholders perceive AMR and how this research them aims to address these gaps.

Chapter 4 presents study 1 of this thesis. This chapter outlines the knowledge, attitudes, and perceptions of dairy farmers to AMR and responsible AMU. The current practices of dairy farmers and their intentions to change their behaviour will be reported. Finally, regression findings are presented to identify predictors of farmers using antimicrobials more responsibly, specifically by stopping blanket use of antimicrobials, and recommend behaviour change interventions which may help farmers overcome barriers and promote more responsible AMU.

Chapter 5 presents study 2 of this thesis. This chapter outlines the knowledge, attitudes, and perceptions of veterinarians in relation to AMR and achieving more responsible prescription of antimicrobials on dairy farms. Findings will report factors which currently influence veterinarians' decision making surrounding responsible AMU and suggest intervention functions which could help veterinarians in their role as antimicrobial stewards.

Chapter 6 presents the third and final study of this thesis. This chapter provides an overview of the facilitated workshop study with stakeholders in the NI dairy industry. It highlights the findings from facilitated discussions, identifying which behaviour change interventions were deemed most feasible and finally proposed interventions to encourage responsible AMU on dairy farms.

Chapter 7 provides a summary discussion of the overall findings of this thesis. The potential impact and policy implications this research may have, the strengths, limitations and suggestions for future work are also discussed in this chapter.

1.4 Ethical approval & funding

Ethical approval was granted by the Faculty of Medicine, Health and Life Sciences Research Ethics Committee at Queen's University Belfast (Reference numbers: MHL 20_123 and MHLS 22_73). All procedures were approved by the School of Biological Sciences and conducted in accordance with the guidelines outlined in the Declaration of Helsinki. Prior to any data collection, all participants involved gave their informed consent to take part in this research. It was made clear to all participants of the three studies that confidentiality would be maintained throughout and all individual data would remain anonymous. Participants in the surveys, interviews and workshop were asked to generate codes which were used for identification rather than recording personal identifiable information such names. Participants were made aware of their right to withdraw from the studies. Those involved in the interviews were advised that they could withdraw at any time

during the interview and survey participants were free to stop completing the online survey at any point and advised that they could withdraw their responses up to two weeks after completion of the survey. All details of study participation, confidentiality, and guidance on withdrawing from the studies were provided via participant information sheets at the beginning of each study.

This project was funded by Department of Agriculture, Environment and Rural Affairs (DAERA; Belfast, UK) as part of the NI Postgraduate Studentship scheme.

1.5 Chapter 1 summary

This first chapter introduces this research. It includes a brief description of the research, specifically, the need for this research, the aims and objectives of this research and presents the contributions made by this work and the layout of subsequent chapters within this thesis.

2. Chapter two: Background

2.1 Antimicrobials

One of the most significant achievements of the twentieth century was the introduction of antimicrobial agents to human and veterinary medicine, changing the entire medical profession and our way of living (Aarestrup, 2015). Antimicrobials are substances that destroy or inhibit the growth of micro-organisms (Ferri et al., 2017; WHO, 2020), a range of different antimicrobial drugs such as antibiotics, antivirals, antifungals and antimalarials exist which are used to fight bacteria, viruses, fungi, and parasites respectively (O'Neill, 2016).

Antimicrobial therapy aims to kill or inhibit the infecting organism without damaging the host. This is commonly accomplished using antimicrobial drugs (Purssell, 2020). The terminology surrounding antimicrobial drugs is complex. For example a strict definition of an antibiotic is that it is a substance produced by one living organism which kills or inhibits the growth of another. This definition excludes synthetic products which are antimicrobials. Many commonly used antimicrobials are true antibiotics, having been isolated from bacteria and fungi however some are now. Penicillin for example is made by a number of fungi in the genus. Many of the antimicrobials in common use are true antibiotics, being isolated from bacteria and fungi, but some are not. For example, penicillin is made by a number of fungi in the genus *Penicillium* and vancomycin by a bacterium known as *Amycolatopsis orientalis*, and both are therefore true antibiotics, while ciprofloxacin and linezolid are synthetic products and so are technically antimicrobials. Some drugs, such as the newer penicillins, are semi-synthetic, which means that they have a natural base that has been altered synthetically (Purssell, 2020).

For the purposes of this thesis the majority of the discussion will refer to the umbrella term of antimicrobial use and antimicrobial resistance.

2.2 Antimicrobial Resistance

Antimicrobial resistance (AMR) is a natural phenomenon which occurs when microorganisms are exposed to antimicrobial drugs. AMR occurs when bacteria, viruses, fungi, and parasites change over time and no longer respond to medicines making infections harder to treat and increasing the risk of disease spread, severe illness, and death. As a result of drug resistance, antibiotics and other antimicrobial medicines become ineffective and infections become increasingly difficult or impossible to treat (WHO, 2020).

AMR has been identified as a major global health challenge of the twenty first century (WHO, 2014a; WHO, 2014b). AMR presents a salient challenge, as the loss of effective antimicrobials might result in common infections becoming life threatening and hinder the ability to perform common surgical procedures and other medical treatments (Mestrovic et al., 2022). Many lifesaving interventions including chemotherapy, organ transplants and major survey rely on effective antimicrobials (Teillant et al., 2015). AMR places both humans and animals at greater risk of prolonged disease or death from bacterial infections (Lambert et al., 2011).

It has been predicted that AMR could result in the global loss of 10 million lives per year by 2050 (O'Neill, 2016) and a comprehensive global assessment of AMR burden in 2019 estimated 4.95 million deaths associated with bacterial AMR and 1.27 million deaths attributable to bacterial AMR in that year alone (Murray et al., 2022). AMR is also contributing to huge socioeconomic costs on a global scale, increased antimicrobial resistance leads to elevated costs associated with more expensive antibiotics, specialized equipment, longer hospital stays and isolation procedures for the patients (ECDC/EMEA, 2009). Social costs include patient death and loss of productivity, in Europe the overall economic burden of AMR was estimated to be at least 1.5 billion euros and productivity loss from infection accounted for 40% of the estimated cost (ECDC/EMEA, 2009). Growing human and animal populations, international travel and trade have been indicated as contributors to the spread of AMR (Harbarth et al., 2015).

The magnitude of the AMR problem has resulted in it being a high priority for health policy makers worldwide (Naranjo-Lucena & Slowey, 2022). Experts have warned that in terms of tackling the burden of AMR, acting quickly is crucial. The development of antimicrobial resistance is evolutionary and is therefore inevitable. However, if resistant infection rates continue to rise so too will the social and economic costs of AMR (O'Neill, 2014).

Despite AMR development being a complex and not fully understood phenomenon, one acknowledged important step in limiting the development of AMR is to limit use and ensure correct usage of antibiotics when needed (WHO, 2020). The inappropriate use of antibiotics has been defined by the World Health Organization (WHO) as including any one of the following; over or under prescribing, inappropriate dosing, incorrect treatment duration or choice of drug and unnecessary use of expensive drugs when older, cheaper and clinically adequate drugs are available (WHO, 2000). "Prudent use" of antibiotics involves decreasing the unnecessary or inappropriate use of antimicrobials to decrease their misuse or overuse so that the efficacy of antibiotics is preserved for as long as possible (Centers for Disease Control and Prevention, 2007). The adoption of prudent antimicrobial practices is deemed essential to minimize selection pressures with the aim of slowing the emergence of antimicrobial resistant bacteria (Aarestrup, 2005).

Antimicrobial resistant bacteria affecting human health have largely arisen due to AMU in human medicine, however the contribution of medicinal use in livestock to AMR is now widely acknowledged (Aarestrup, 2005). There is scientific recognition that the widespread use of antibiotics in agriculture may contribute to the development of resistance to antibiotics which are commonly used in human medicine (WHO, 2000). Bacteria which are treated with antibiotics in animals, can develop antibiotic resistance and such bacteria may be transmitted from infected

animals to humans (Landers et al., 2012). Resistant bacteria can be transferred to humans through the food chain or from direct contact with animals infected by resistant bacteria (Black, 1984; Espinasse, 1993).

The development of new antimicrobial drugs has been deemed necessary in the fight against AMR. However, the facilitation of such research is costly and the emergence of bacterial resistance in previous newly developed compounds has always been quick to emerge. Following the introduction of new antimicrobial compounds, in all known cases, antimicrobial resistance has been observed (Levy, 1982). For many of the classes of antibiotics developed thus far, resistance has emerged on average five years after commercial release (Harbarth et al., 2015). New effective antimicrobials are therefore unlikely to be developed at a sufficient rate to meet demand (Norrby, Nord and Finch, 2005) and so, experts globally are faced with the major challenge of finding alternative ways to combat bacterial pathogens or find ways to delay the development of resistance (Aarestrup, 2015).

Existing antibiotic consumption is one of the main drivers of AMR and so prudent use must be a priority (Laxminarayan & Van Boeckel, 2014). The adoption of prudent antimicrobial practices in veterinary as well as human medicine is essential to minimize selection pressures with the aim of slowing the emergence of antimicrobial resistant bacteria (Aarestrup, 2005). It is widely acknowledged that research and policy efforts towards reducing antibiotic use in animal husbandry are needed (FAO, 2016).

2.3 Antimicrobial use in agriculture

The introduction of antimicrobial agents in agriculture caused a revolution in the treatment of many infectious diseases observed in food producing animals, as well as attempts to reduce or eradicate specific diseases (Prescott, 2009). Antimicrobials are essential for maintaining health in the treatment of bacterial diseases and therefore play an important role in the care of food producing animals. Healthy, productive animals are considered likely to provide high quality food for human consumption at a lower cost (Oliver et al., 2011). The use of antibiotics has demonstrated many benefits in livestock production, including improved animal health, higher production levels and a reduction in foodborne pathogens (Mathew et al., 2007). As with human medicine, antimicrobial agents are used in modern food-animal production therapeutically for the treatment of specific infections in clinically sick animals (Barton, 2014). Antimicrobials have also been used extensively in veterinary medicine for the prevention of disease in food producing animals (Barton, 2014). The use of antimicrobials for growth promotion in livestock is one of the most controversial methods. The discovery of the growth promoting potential of antimicrobial agents was made in the 1940's (Moore et al, 1946). Soon after this discovery, antimicrobial growth promoters (AGP’s) were approved for

use and were commonly used in the USA and the UK since 1949 and 1953 respectively (Swann, 1969).

The majority of antimicrobial drugs sold globally (73%) are used in animals raised for food (Van Boeckel et al, 2017), raising concerns about the selection of resistance and its migration from livestock and their environment to humans. AMR associated with livestock can enter humans through consumption of animal products such as contaminated meat and dairy products or more indirectly through land-application of animal waste and connected water resources (Baker et al., 2022). The potential association between antimicrobial use in food producing animals and the emergence of AMR in animals and potentially humans, dates back to the Swann Report more than four decades ago (Swann et al., 1969).

The misuse and overuse of antimicrobials in food producing animals has aided the emergence of resistance which poses consequences for animal health as well as human health (Coyne et al, 2016). For farmers, animal husbandry and the food industry, the loss of effective antimicrobial agents to treat sick animal's damages food production and family livelihoods. An additional risk for livestock workers is exposure to animals carrying resistant bacteria (WHO, 2015a). Agricultural AMU poses a risk for the emergence and spread of AMR as well as the transfer of resistance related genes between bacterial species and populations (Palma et al., 2020). Such resistance may be passed on down the food chain and potentially compromise human health (Paphitou, 2013).

2.3.1 Antimicrobial use in dairy cattle

Antibiotics are routinely administered to dairy cattle for treatment or prevention of common illnesses, including mastitis, respiratory disease, lameness and enteric diseases (Andrews, 2000; Dodd and Booth, 2000; Oliver et al., 2011). Intramammary infections (IMI) cause mastitis, a common occurrence affecting animal welfare and economics in dairy herds worldwide (Huijps et al., 2008; Lam et al., 2013; Naranjo-Lucena & Slowey, 2022). Control of mastitis can be challenging, due to the high number of subclinical infections that go undetected but still lead to reduced milk production, and to the withdrawal periods that treatment in dairy cattle follow to control for antimicrobial residues in milk for human consumption. (Naranjo-Lucena & Slowey, 2022)

Intramammary infections can occur in clinical, subclinical forms, or asymptomatic forms. Clinical forms may take an acute or chronic course of infection, but pathological signs such as swelling, heat, hardness, redness or pain of the udder, changes in the milk appearance, and reduction of milk yield can always be observed (Argaw, 2016). However, subclinical infections are not visible externally, but cause production losses and changes in milk parameters (Naranjo-Lucena & Slowey, 2022).

To reduce the prevalence of IMI, dry cow therapy (DCT) aims to eliminate IMI already present at drying-off and prevent new IMI during the dry period using antimicrobials (Bradley & Green, 2001). Blanket dry cow therapy (BDCT) involves the prophylactic antibiotic treatment of every cow at drying off, irrespective of their clinical status, to prevent infection and historically has been used in mastitis control (Biggs, 2017; Neave et al., 1969). As this practice involves treating all cows with antimicrobials, even those who are not infected at drying off, BDCT has been linked to the threat of AMR development (Brunton et al., 2012; Higham et al., 2018). Selective dry cow therapy (SDCT) is a commonly promoted alternative, in which only cows shown to be clinically infected with mastitis receive antibiotic treatment (Huey et al., 2021).

Resistance to antimicrobials has been previously associated with the treatment of mastitis and dry cow therapy as well as feeding waste milk containing antibiotic residues to calves (Bryan and Hea, 2017; Brunton et al., 2012). Inappropriate use of antimicrobials, such as in the blanket treating of all cows as a preventative measure, is thought to contribute to AMR in dairy farming (Gruet et al., 2001). Waste from dairy production is one of the largest sources of contamination from antimicrobial resistant bacteria and genes in many parts of the world (Baker et al., 2022). With high dairy production in much of the world, dairy waste represents a substantial route for AMR to enter the environment, including onto fields and grasslands used for food production and into water ways (Baker et al., 2022).

2.4 Tackling imprudent antimicrobial use in dairy cattle

In response to the risk of AMR globally, the World Health Organization (WHO) created a set of strategies to combat rising AMR. Strategies include the improvement of sanitation and hygiene to reduce infection rates and optimizing the use of antibiotics in both human and animal medicine (WHO, 2015a). Many countries have made national efforts to reduce their overall antibiotic use in agriculture, strategies for this include the creation of national AMU reduction targets, introduction of mandatory bans on antimicrobial drugs in feed for food producing animals, benchmarking of on farm AMU and the encouragement of antimicrobial stewardship programs (EMA & EFSA, 2017).

Antimicrobial stewardship programs were introduced in the veterinary sector in Denmark as early as 1998, when the use of antibiotic growth promoters (AGPs) in weaning pigs was ceased. Ten years later, the average daily weight gain for each animal was 20% higher than prior to the ban, demonstrating that weight gain in livestock is achievable without the use of AGPs (Agerson & Aarestrup, 2013). Veterinary AMU has halved since 2010 in the Netherlands due to more stringent AMU regulations (Nethmap/Maran, 2016), and data suggests that it has led to a noticeable decline in resistance levels in livestock (Dorado-Garcia et al., 2016).

In January 2019 the UK Government published the 'UK Five Year National Action Plan: Tackling Antimicrobial Resistance 2019-2024, with the vision of a world with effective containment and control of AMR through strong mitigation. The UK plans to contribute to this global effort through a lower burden of infection, optimal AMU and new diagnostics, therapies, vaccines and interventions (UK Government, 2019). In 2017, the United Kingdom's Responsible use of Medicines in Agriculture Alliance (RUMA), published a targets task force report which set out sector specific targets for AMU reduction in UK agriculture by 2020 (RUMA, 2017). Specific farm management practices have been suggested to reduce the need for antimicrobials. Suggestions include: the use of vaccines, probiotics and immune enhancers to mitigate disease risk, proper nutrition and diet, as well as improved operational procedures such as buying from herds with higher herd health status, pre-arrival animal testing, the use of quarantine facilities and the elimination of contaminated feed and water (U.S Department of Agriculture, 2007). Regulation (EU) 2019/6 on Veterinary Medicinal Products sets out the control of veterinary medicines, under this directive, all veterinary medicines, including those containing antibiotics, require authorization before they can be marketed or administrated. In the UK, all veterinary medicines must be prescribed by a veterinarian. Routine prophylactic use of antibiotics as a disease prevention method is not recommended practice in the UK (UK Government, 2014), and the use of antibiotics as growth promoters has been banned in the EU since 2006 with the introduction of Regulation 1831/2003/EC on additives for use in animal nutrition. The ban was fueled by growing concerns over the development of AMR and the potential transfer of antibiotic resistance genes from animals to humans (Castanon, 2007).

Bans or restriction policies on antimicrobial use have achieved impressive results in the veterinary sector in some countries (Levy, 2014). In the UK the consumption of antimicrobial drugs sold for veterinary purposes decreased by 48% from 2013-2017 (Veterinary Medicines Directorate, 2019). Efforts have already begun in the UK dairy industry to reduce total AMU. By the end of the first year of the RUMA targets existence, the total AMU in UK dairy cattle was 17mg/kg, a 29% reduction from the estimated 2016 baseline (RUMA, 2018). Injectable HP-CIA (highest priority, critically important antibiotic) products licenced for cattle were 0.24mg/kg in 2021, representing an 18% reduction since 2020 (0.29mg/ kg). And intramammary HP-CIA products in 2021 were 0.02mg/ kg which is the lowest they have been and represents a 96% reduction since the 2014 baseline (RUMA, 2022). A recent systematic review and meta-analysis aimed to assess whether restricting the use of antibiotics in food producing veterinary medicine leads to reductions in the presence of antibiotic resistant bacteria in food producing animals and humans. The review concluded that interventions which aim to restrict antibiotic use in food producing animals are associated with a reduced antibiotic resistance presence in such animals (Tang et al., 2017).

2.4.1 Importance of farmer and veterinarian perceptions

Measuring AMU is challenging (WHO, 2015b; O'Neill, 2016; Kallen et al., 2019), and this is particularly true when it comes to the measurement of agricultural and veterinary AMU (Mills et al., 2018). An accurate understanding of AMU in animal health is essential to understanding patterns of resistance and informing antimicrobial stewardship policy making (O'Neill, 2016). A recent UK government action plan specifically advocates for "a clear need for more robust data on how antimicrobials are used to improve our understanding of the links between animal health and welfare, productivity, drug usage and resistance and to provide the evidence needed to design effective interventions and controls" (UK Government, 2019).

In terms of policy making and health scheme implementation, the understanding of attitudes and factors which influence the decision-making process, and the translation of behavioural intentions into sustained behaviour change is an increasingly useful discipline (Jones et al., 2015). Studies are needed to better understand the reasons behind certain practices relating to AMU in agriculture in order to implement effective interventions promoting prudent AMU on farms (Fischer et al., 2019). Understanding farmers' motivations to implement such recommended prudent antibiotic practices needs to be better explored to reduce and refine the use of antimicrobials on dairy farms (Poizat et al., 2017). It is necessary to explore if dairy farmers are knowledgeable and engaged in food practices which protect both animals and humans from antibiotic resistance and disease transfer (Friedman et al., 2007). Previous relevant qualitative work revealed that a range of factors may contribute to dairy farmers AMU, suggested factors include their awareness of AMR, the complexity or strictness of AMU regulation, animal health and welfare, lack of time, financial factors and the farmer-veterinarian relationship (Jones et al., 2015, Kumar & Gupta, 2018, Kramer et al., 2017, Higham et al., 2018, Fischer et al., 2019, Friedman et al., 2007). Previous research has called for the characterization of farmer's AMU as well as the identification of key drivers towards responsible AMU among dairy farmers. It is anticipated that such research findings can lead to the identification of farmer led solutions to reducing, replacing and refining AMU on dairy farms (Higham et al., 2018).

Farmers' use of antibiotics does not occur independently, it is rather, an outcome of society's agency-structure relationship. This means that it is a result of a combination of factors which can include but is not limited to farmers own ideas and practices, veterinary advice, regulatory restrictions, peer pressure from neighbors and interactions with their animals (Burton et al., 2012; Hamilton, 2017). Veterinary services can play an important role in identifying and recommending farming practices that promote animal health and productivity while reducing extensive antibiotic use (U.S. Department of Agriculture, 2007). Even with the existence of veterinary medicine regulations and on farm AMU reduction campaigns, how veterinary medicines are prescribed is

largely down to the professional judgement of each individual veterinarian and may be influenced by various factors. Farm management practices or social factors are suggested to be involved in veterinarians' decision making (Grave et al., 2010). Veterinarians' treatment choices may also be influenced by farmers' opinions and needs such as their financial situations, withdrawal periods and the ease of administration of the prescribed drug (De Briyne et al., 2013: Gibbons et al., 2013). Once antimicrobials are prescribed to farmers the veterinarian is unaware of how such drugs are administered and managed by the farmers which is an additional concern for veterinarians in regard to their antimicrobial prescribing decision-making process. (Jones et al., 2015).

Dairy farmers have previously stated that their relationship with their veterinarian is one of trust and believe that the veterinarian's role in dairy farmers AMU is one of authority (Higham et al., 2018, Fischer et al., 2019, Friedman et al., 2007). One study previously noted that dairy farmers who had greater awareness of AMR also had more visits from or contact with their veterinarian (Higham et al., 2018). These findings highlight the pivotal role veterinarians can play in antimicrobial stewardship and farmer engagement in the issue of responsible AMU at farm level. It was recently recommended that veterinarians adopt a more mutualistic, relationship centered communication style with farmers rather than a paternalistic, directive style (Bard et al., 2017). This supportive communication style may benefit attitudinal change towards acceptance of AMU regulations and reduce pressures on veterinarians to prescribe antimicrobials for dairy cattle. Strengthened farmer-veterinarian relationships are considered desirable for ensuring more responsible antimicrobial practices (Kramer et al., 2017).

As the use of antimicrobials is a key contributor to the development of AMR, it is important to assess the AMU behaviours of key stakeholders responsible for antimicrobial prescription and administration (Friedman et al., 2007). To help promote responsible AMU on dairy farms, understanding both farmer and veterinarians AMU behaviour and attitudes towards AMR can identify factors and motives which may be important influencers of current and proposed prudent AMU practices (Busani et al., 2004). Both dairy farmers and veterinarians play a key role in the use of antimicrobials at farm level and have a responsibility to work towards prudent AMU in dairy cattle production. There is therefore a need to explore the knowledge, attitudes and perceptions each stakeholder has to AMU and AMR and their acceptance of interventions aimed at achieving prudent AMU in the dairy sector. In addition to this, the exploration of the farmer-veterinarian relationship from both perspectives, in regard to achieving their common goal of prudent AMU within the dairy sector, could help shape positive relationships and successful implementation of AMU best practice recommendations. Ultimately a good working relationship between dairy farmers and veterinarians

on the island of Ireland will result in reduced AMU in the sector and a reduction in the threat of AMR to human and animal populations.

2.4.2 Importance of behaviour change theory

Human behaviours play an important role in both driving and mitigating AMR (Borek et al., 2022). As behaviours, they are influenced by factors and processes that shape all human behaviour. AMR is a complex issue requiring multidisciplinary approaches, however, behavioural science can help with understanding and changing relevant behaviours of prescribers and users of antimicrobials (Borek et al., 2022). Understanding behaviour and promoting behaviour change related to AMR has been recommended in global and national action plans to address AMR (Department of Health & Social Care, 2019; WHO, 2015a). The role of behaviour change theory in AMR and antimicrobial stewardship has been increasingly recognized in previous research (Charani et al., 2014; Bassetti et al., 2019; Tonkin-Crine et al., 2015). There is growing evidence that behavioural interventions are effective in addressing AMR related behaviours in human healthcare (such as reducing clinically unnecessary antibiotic prescribing), thus supporting the use of behavioural science (Cuevas et al., 2021; Davey et al., 2017).

The utilisation of theoretical frameworks for identification of barriers and enablers to prescribing can result in the development of antimicrobial stewardship interventions that may be successfully implemented and sustained (Craig et al., 2008; Ierano et al., 2019). A number of theoretical models exist that offer explanations of the complexities underlying human behaviour and behaviour change. For example, the Theory of Planned Behaviour (Ajzen, 1991) and The Transtheoretical model (Prochaska, 1997). Increasingly, these models are being used in agricultural research surrounding AMU by veterinarians (Jones et al., 2015; Coyne et al., 2016; Visschers et al., 2016a), explaining prescribing behaviour using a set of intrinsic motivational factors and extrinsic enabling or inhibiting stimuli for performing responsible behaviours. One common limitation of these theories is that they only help to understand or predict behaviours (Kok et al., 2004) and do not help to understand behaviour change (Brug et al., 2005) or develop interventions.

Behavioural determinants are the types of factors that influence (facilitate or impede) behaviour and behaviour change (Borek et al., 2022). Behavioural determinants identified in behaviour change theories have been synthesized, organized, and defined in the theoretical domains framework (TDF) (Cane, O'Connor & Michie, 2012). The Theoretical Domains Framework (TDF) brings together 33 models of behaviour or behaviour change and includes 128 separate constructs (Michie et al., 2005). The TDF has 11 theoretical domains that explain the potential determinants of behaviour (*knowledge, skills, social/professional role and identity, beliefs about capabilities, beliefs about*

consequences, motivation and goals, memory attention and decision processes, environmental context and resources, social influences, emotion, and action planning). Subsequent development of the TDF led to validation (Cane, O'Connor & Michie, 2012) with 14 domains where *optimism, reinforcement* and *intentions* were identified as important and added (rather than being embedded in the earlier 11). Use of the COM-B helps identify domains of the TDF most likely to influence a particular behaviour change.

2.4.2 The COM-B model of behaviour change

The British Psychological Society (BPS) Behavioural Science and Disease Prevention Taskforce (BPS, 2020) recommends using the COM-B model for exploring behavioural influences and the design of behaviour change interventions. The COM-B model (Figure 1) proposes that behaviour is a result of interactions between three interrelated components: capability, opportunity, and motivation (Michie, van Stralen & West, 2011). The model proposes that an individual must have sufficient levels of capability (psychological and physical, e.g., knowledge, skills), opportunity (physical and social, e.g., time, social cues) and motivation (reflective and automatic e.g., intentions and planning) in order for a target behaviour to change (Michie, van Stralen & West, 2011).

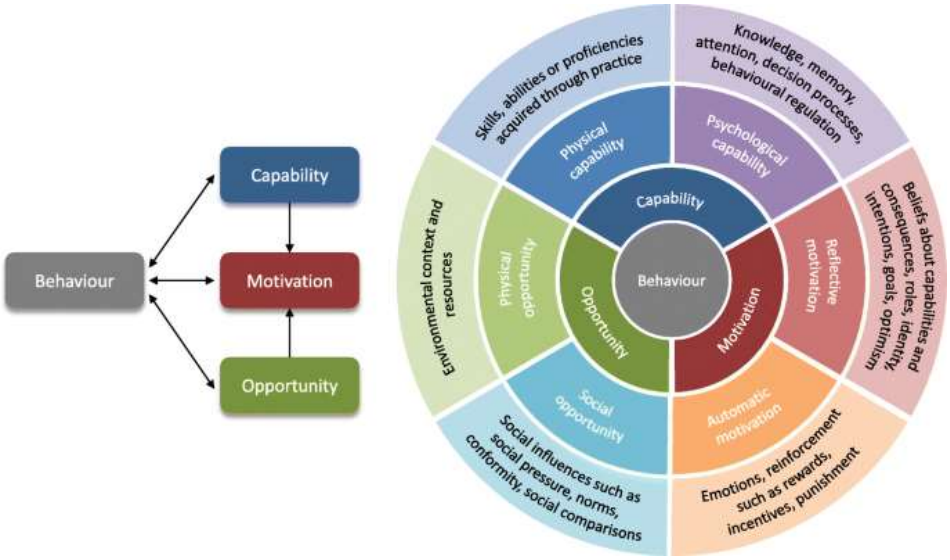


Figure 1: The COM-B model of behaviour change

The COM-B model accounts for cognitive factors as well as the impact of non-cognitive factors such as external factors (e.g., the physical environment and social influences) (Michie, van Stralen & West, 2011). The COM-B model has been developed based on an extensive review of existing behaviour change theories, evolving the study of human behaviour from a unidimensional focus on a limited number of individual factors. Instead, it understands behaviour as a product of many different levels of influence, providing a more holistic study of human behaviour (Michie, van Stralen & West, 2011; Regan et al., 2021)

Strengths of the COM-B Model: The COM-B model recognises that behaviour is influenced by many factors, and it allows for a comprehensive approach to behaviour change. COM-B is rigorous and evidence-based and offers a structured approach to identifying barriers to behaviour. The COM-B model can be presented at different levels of complexity, making it particularly useful to engage stakeholders from different educational backgrounds in behaviour change intervention design and evaluation (Michie, van Stralen & West, 2011).

Limitations of the COM-B Model: Although it has been praised for enabling systematic categorisation and replication of behaviour change interventions, some authors have argued that COM-B obviates variability in behaviour by reducing it to capability, opportunity and motivation (Ogden, 2016; Abraham, 2016). COM-B is an academic model which has been used mostly in the context of health behaviour, and so its application to other contexts may be less straightforward however some examples of its application in agricultural research exists.

To help researchers transition from the behavioural diagnosis of a problem to the design of an intervention, the Behaviour Change Wheel (BCW) was developed (Michie, van Stralen & West, 2011; Michie, Atkins & West, 2014) from 19 behaviour change frameworks. The COM-B model is at the centre of the behaviour change wheel (BCW), a tool kit used in the design of behaviour change interventions (Michie, Atkins & West, 2014).

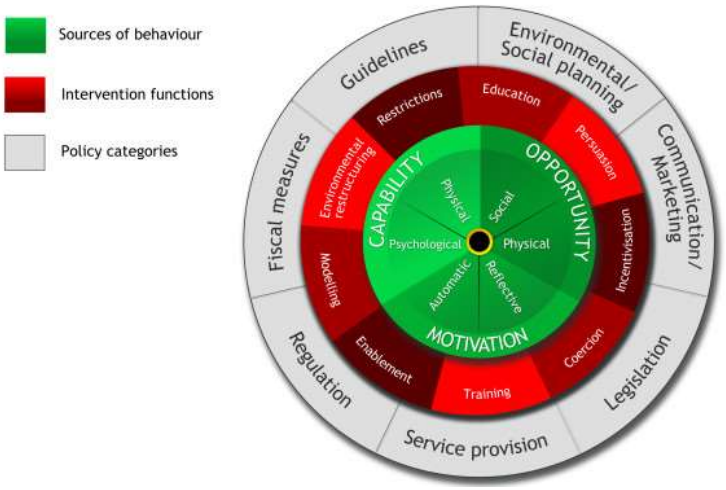


Figure 2: The behaviour change wheel (Michie et al., 2014)

The BCW consists of three layers (Figure 2), the hub of the wheel identifies the sources of behaviour and uses the COM-B model. Surrounding this is a layer of nine intervention functions that can be used to address one or more deficits in capability, opportunity, or motivation. These intervention functions can then be linked to the outer layer which consists of seven policy categories that one can use to deliver the intervention functions. The BCW does not provide a detailed blueprint for the design of behaviour

change interventions but does provide a systematic and theoretically guided method for identifying the types of interventions and supporting policies that would be expected to be effective for a given behaviour, context and target individual, group, or population (Michie, Atkins & West, 2014). Using the matrixes in tables 1 and 2 below, the findings of the studies of farmers and veterinarians within this thesis will be linked to suitable intervention functions and policy categories, in order to propose potential behaviour change interventions to help achieve more responsible AMU on dairy farms.

Table 1: Matrix of the links between COM-B components and intervention functions

	Intervention functions								
COM-B Components	**Education**	**Persuasion**	**Incentivisation**	**Coercion**	**Training**	**Restriction**	**Environmental restructuring**	**Modelling**	**Enablement**
Capability – physical					■				■
Capability – psychological	■				■				■
Opportunity – physical					■	■	■		■
Opportunity – social						■	■	■	■
Motivation – Automatic		■	■	■	■		■	■	■
Motivation – reflective	■	■	■	■					

(Table adapted from Michie et al., 2014)

Table 2: Matrix of the links between intervention functions and policy categories

	Intervention functions								
Policy categories	**Education**	**Persuasion**	**Incentivisation**	**Coercion**	**Training**	**Restriction**	**Environmental restructuring**	**Modelling**	**Enablement**
Communication/Marketing	■	■	■	■				■	
Guidelines	■	■	■	■	■	■	■		■
Fiscal measures			■	■	■		■		■
Regulation	■	■	■	■	■	■	■		■
Legislation	■	■	■	■	■	■	■		■
Environmental/Social planning							■		■
Service provision	■	■	■	■	■			■	■

(Table adapted from Michie et al., 2014)

Rationale for choosing to use the COM-B model and BCW for this research:

The COM-B model is an established method for understanding behaviour and used extensively in behaviour change interventions (Timlin et al., 2021). The COM-B model has been used widely in

human healthcare and consumer research to improve hearing aid use (Barker et al., 2016), to encourage higher welfare food choices (Cornish et al., 2019), medication adherence (Jackson et al., 2014) and smoking cessation (Kwah, Fulton & Brown, 2019). The use of this behaviour change theory in agriculture is limited (Kropf et al., 2020; Irwin et al., 2021; Regan et al., 2021) and more specifically has not yet been applied to responsible AMU in dairy farming.

Application of the COM-B model to key AMU behaviours of dairy farmers and veterinarians can help provide an understanding of the components which are most likely to influence responsible behaviour amongst dairy farmers and veterinarians, thus enabling identification of appropriate targets for behaviour change interventions to promote more responsible AMU on dairy farms. Given the objective of this thesis to propose behaviour change interventions to promote more responsible AMU on dairy farms, the COM-B model of behaviour change was deemed the most suitable model of behaviour change. The COM-B model can be used to design behaviour change interventions in a systematic manner which could be easily followed by the researcher (Michie, Atkins & West, 2014).

2.5 Chapter 2 summary

Chapter 2 presents background information on antimicrobials, antimicrobial resistance and antimicrobial use in agriculture, specifically antimicrobial use on dairy cattle. Further, chapter 2 highlights the need to promote more responsible AMU on dairy farms and the importance of incorporating behaviour change theory when researching dairy farmer and veterinarians AMU behaviours. Antimicrobials are vital for maintaining human and animal health, irresponsible use in both human and animal medicine can lead to the development of resistance, threatening the ability to treat common infections and disease. The need for responsible AMU in agriculture is acknowledged as a vital strategy in tackling the global threat posed by AMR. Dairy farmers and veterinarians are the key stakeholders responsible for AMU in dairy cattle and so it is important that their behaviours and practices surrounding AMU are fully understood in order to identify the steps which can be taken to empower them to make sustainable, responsible changes. Application of behaviour change theory is vital to ensure that interventions proposed to overcome current barriers to responsible AMU in dairy cattle, have the greatest chance at being effective and successfully implemented.

3. Chapter three: Systematic review

3.1 Introduction

Antimicrobial resistance (AMR) occurs naturally when microorganisms are exposed to antimicrobial drugs. Under selective pressure, susceptible bacteria are killed or inhibited, and bacteria that are naturally resistant or have acquired AMR have a greater chance of survival and risk of disease spread (Prestinaci, Pezzotti and Pantosti, 2015). Antimicrobial resistance is a major global health challenge (WHO, 2014a; WHO, 2014b): many lifesaving interventions such as chemotherapy and organ transplant rely on effective antimicrobials (Teillant et al., 2015), so AMR places humans and animals at substantial increased risk of prolonged illness or death from infection (Lambert et al., 2011). Experts have warned that if AMR continues to rise, so too will the associated social and economic costs (O'Neill, 2014).

Limiting antimicrobial use (AMU) is a vital step in limiting the development of AMR (WHO, 2020). Inappropriate AMU includes over- or under prescribing, inappropriate dosing, incorrect treatment duration or drug choice, and unnecessary use of expensive drugs when established, cheaper, and clinically adequate drugs are available (WHO, 2000). "Prudent use" of antimicrobials involves avoiding inappropriate AMU to preserve antimicrobial efficacy for as long as possible (Centers for Disease Control and Prevention, 2007).

Antimicrobial use in agriculture can lead to resistance in the environment and implications for public health (Manyi-Loh et al., 2018). It is widely acknowledged that research and policy efforts are needed to reduce agricultural AMU (FAO, 2016). A recent systematic review concluded that interventions that aim to restrict AMU in livestock are associated with reduced AMR in such animals (Tang et al., 2017).

Understanding stakeholder attitudes, decision-making, and the translation of behavioural intentions into sustained behaviour change is an increasingly important discipline for policy design (Jones et al., 2015). Studies that explore the reasons for current AMU in agriculture are needed to design effective interventions to promote prudent agricultural AMU (Fischer et al., 2019). Monitoring of AMU in livestock alone reveals little about what drives AMU, so it is important to assess the behaviours of key stakeholders responsible for antimicrobial prescription and administration (Friedman et al., 2007).

It is important to understand the AMU behaviours of dairy farmers and veterinarians and their attitudes toward AMR to identify how their beliefs and motives influence their AMU (Busani et al., 2004). It has been reported that understanding farmers' motivations to implement recommended practices is necessary for reducing AMU (Poizat et al., 2017) and for measuring knowledge and

behaviours that protect both animals and humans from AMR and disease transfer (Friedman et al., 2007). In addition, on-farm AMU needs to be characterized and the key drivers of responsible AMU identified; such findings may be able to inform interventions to reduce AMU on dairy farms (Higham et al., 2018).

Both qualitative and quantitative research methods have been used to explore topics such as the knowledge, attitudes, and perceptions of dairy farmers and veterinarians with respect to AMR and their individual AMU practices. Such research methodologies focus on one or two of these areas and have presented a range of findings; research exploring all of the above factors is scarce. Previous studies have not followed a common methodology, and the aims of such articles have been broad-ranging. To obtain a more in-depth knowledge of what is currently known, this review aimed to collate and synthesize all available published data relating to the knowledge, attitudes, and perceptions of dairy farmers and veterinarians with respect to AMR and their individual AMU practices. This will provide a coherent picture of what is currently known, identifying commonalities and contradictions in findings between studies and identifying gaps in the current knowledge to inform future behavioural analysis research and AMU intervention design.

3.2 Materials and methods

3.2.1 Review Approach

This review was reported in accordance with the Enhancing Transparency in Reporting the Synthesis of Qualitative Research (ENTREQ) framework, a reporting guideline for the synthesis of qualitative research (Tong et al., 2012). To address the research question, articles of interest were those that explored the knowledge, awareness, attitudes, and perceptions of dairy farmers and dairy veterinarians with respect to AMU and AMR.

3.2.2 Search Strategy

In November and December 2019, a pre-planned, comprehensive, systematic search of electronic databases was undertaken to seek all available studies related to the research question. To obtain relevant articles, literature searches were conducted in Embase, Medline, PubMed, Scopus, and Web of Science. Articles included in the review were obtained predominantly via databases and, where applicable, additional articles were retrieved from the reference lists of published articles.

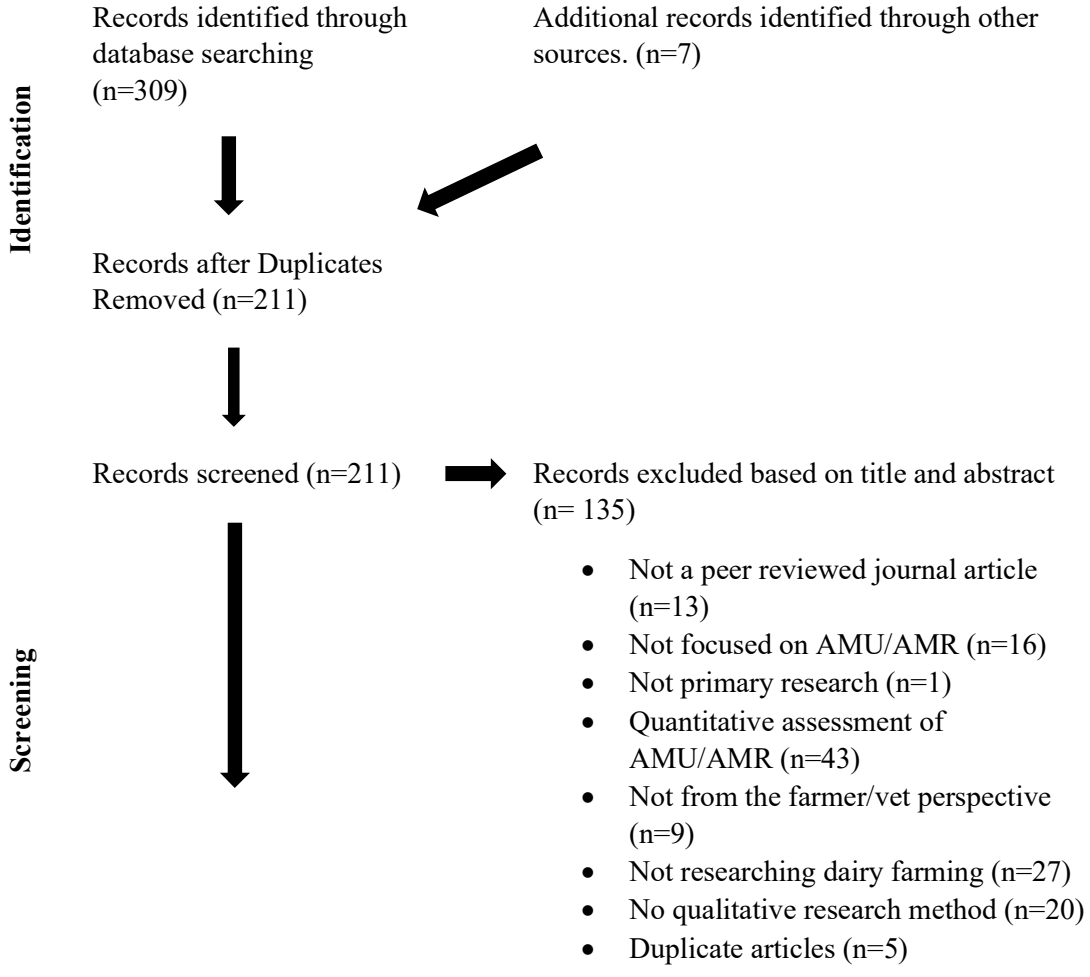
The search terms used in the databases included “dairy farmer,” “dairy veterinarian,” “antimicrobial use,” antibiotic use,” and “antimicrobial resistance.” Each database was searched multiple times using combinations of the previously mentioned terms to yield as many relevant articles as possible. Full details of the search terms used, and results yielded from each database search is available in appendix 1. The search criteria for this review was limited to published peer-reviewed articles

available in English and placed no publication date limits on the database searches. Only peer-reviewed journal articles aiming to explore the knowledge, awareness, attitudes, or perceptions of dairy farmers or veterinarians were included in the review. Studies that used surveys, questionnaires, interviews, and focus groups were included.

3.2.3 Screening and Data Extraction

Articles were retained for review if the study population consisted of or included dairy farmers and dairy veterinarians. Articles were excluded if the research was focused on the quantity of AMU on farms, did not focus on dairy farmers' or veterinarians' perspective with respect to AMU or AMR, or if no independent research method was outlined. Following the removal of duplicates, articles obtained from all sources were screened for eligibility based on title and abstract (n = 211). Articles were deemed eligible if they met the outlined inclusion criteria. Following a full-text review of the remaining articles (n = 76), those deemed eligible (n = 35) were retained for the systematic review.

Articles were included only if the data-collection methods were adequately outlined (i.e., if they gave details of the study population, sampling method, and data analysis). Figure 3 illustrates the process of searching, screening, and identifying studies for inclusion in this systematic synthesis.



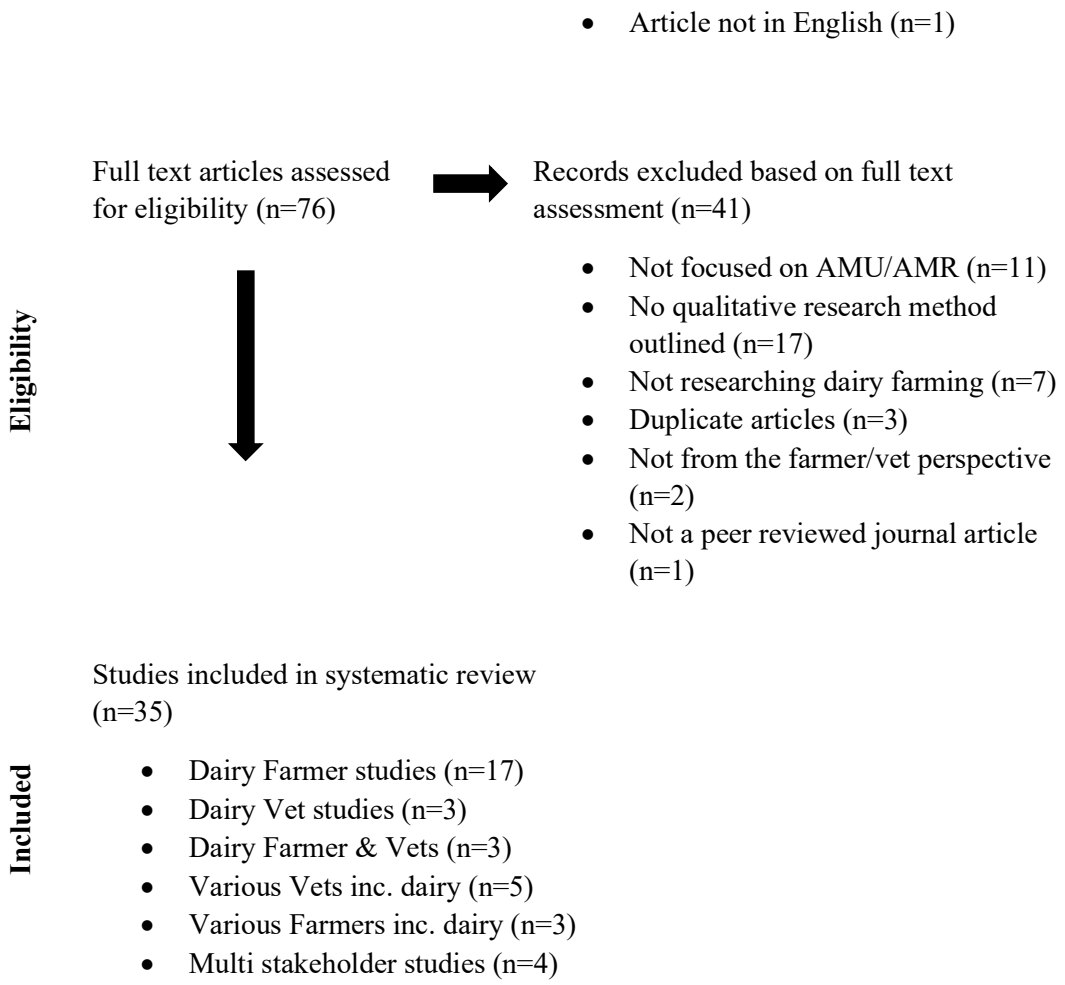


Figure 3: PRISMA flow diagram of literature review process for studies on dairy farmer and veterinarians' current practices, attitudes & perceptions of AMR and reducing AMU.

For each of the articles identified as eligible for this review, all text under the headings "Results" were extracted from the articles and exported into qualitative data analysis software NVivo 12 (QSR International Pty Ltd., Doncaster, Victoria, Australia) for data synthesis. Transparency of reporting was assessed for each study using the Consolidated Criteria for Reporting Qualitative Research (COREQ) framework (Tong et al., 2007). The quality of the included studies was assessed using the Critical Appraisal Skills Programme Qualitative Research Checklist (Critical Appraisal Skills Programme, 2017). Appraisal was conducted by the main researcher (SF), and then discussed and agreed upon with the other members of the research team at QUB (MD, TB, CMcK). No study with data relevant to the aim of the review was excluded from the synthesis.

3.2.4 Data Analysis

Extracted findings were thematically analysed inductively, in line with the Braun and Clarke (2006) protocol, allowing for themes to be constructed from the data. Extracted findings from each article were coded line by line to search for information of interest to the research question. All data

relating to farmers' and veterinarians' knowledge, awareness, attitudes, and perceptions with respect to AMR and reduced AMU were coded. Codes were then grouped along with their related data into potential themes, identifying overlap and commonalities, and themes were refined where necessary (i.e., collapsed or divided). At this stage, extracted findings were re-read to ensure that no data had been missed in earlier coding stages. Coding was performed by the main researcher (SF) and reviewed and approved by two additional researchers from QUB (MD and TB).

3.3 Result & discussion

Thirty-five studies, which collected data from 5,537 participants, were deemed relevant for this review. An overview of the study characteristics is presented in Figure 4. The study population was exclusively farmers in 20 articles (only dairy farmers in 17 articles), exclusively veterinarians in 8 articles (only dairy veterinarians in 3 articles), and a multi-stakeholder study population that included dairy farmers and dairy veterinarians in 7 articles. Just over half of the studies used surveys as the data-collection method (54.3%); interviews (25.7%), mixed methods (14.3%), and focus groups (5.7%) were also used. Studies were conducted in mainland Europe (14), the United States (8), the United Kingdom (5), Asia (3), South America (2), North America (1), Oceania (1), and Africa (1). All included studies were published between 2002 and 2019. Thematic analysis identified 5 key themes in the data; themes and sub-themes are presented in Figure 5.

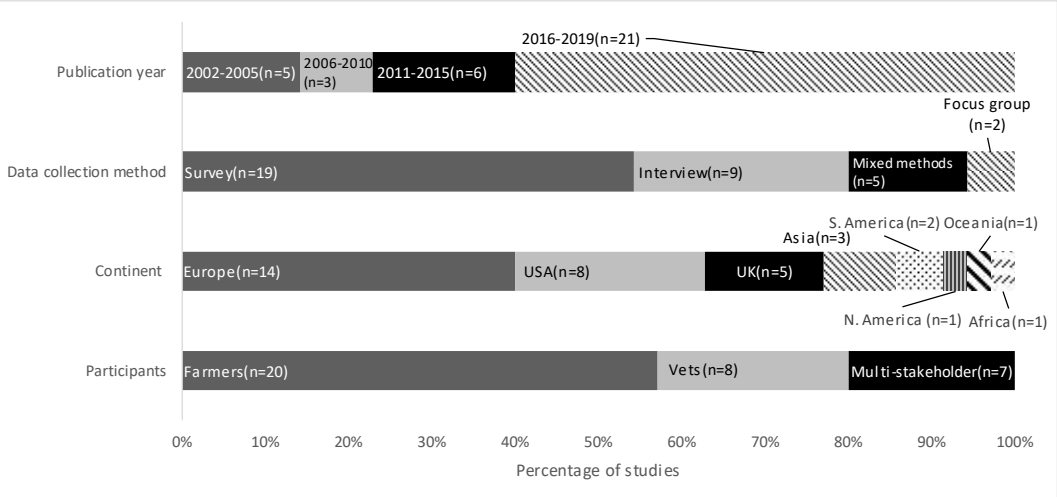


Figure 4: Summary of review study characteristics (n=number of studies)

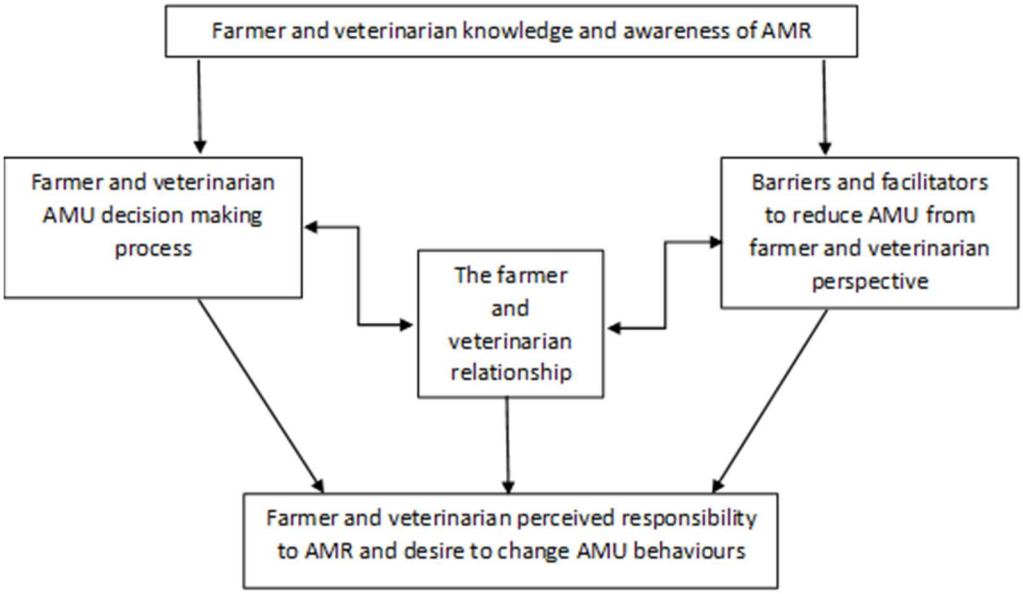


Figure 5: Overview of key themes identified through thematic analysis

Table 3 below summarizes the key findings and recommendations based on the systematic review.

Table 3: Summary of the main review findings and recommendations made in relation to achieving reduced antimicrobial use on dairy farms based on systematic review

Recommendations made based on systematic review	Relevant stakeholder	Findings to support recommendation	References
<u>Increased knowledge</u> On AMR[1] in dairy cattle, its impact on human AMR and the role farmers and veterinarians can play in the development and spread of AMR	Dairy Farmers and Dairy Veterinarians	Variations in knowledge and awareness of AMR in dairy cattle. Lack of knowledge regarding the link between animal and human AMR. Imbalance in farmer and veterinarian's recognition of their role in AMR	Higham et al., 2018; Raymond et al., 2006; Friedman et al., 2007; Redding et al., 2014; Sadiq et al., 2018; Chauhan et al., 2018; Jones et al., 2015; Poizat et al., 2017; Kumar & Gupta 2018; Ekakoro et al., 2018; Speksnijder et al., 2015; Léger et al., 2015; Golding et al., 2019; Swinkles et al., 2015; McDougall et al., 2017; Magalhaes Sant'Ana et al., 2017; Cattaneo et al., 2009
How economic risks can be minimised while reducing on farm AMU[2]	Dairy Farmers Dairy Veterinarians	Concerns due to economic risks associated with reducing AMU on farm such as animal mortality and farm productivity	Raymond et al., 2006; Friedman et al., 2007; Speksnijder et al., 2015; Magalhaes Sant'Ana et al., 2017; Fischer et al., 2019; Golding et al., 2019

Skill development Improved ability and confidence to implement prudent AMU practices while maintaining animal welfare standards	Dairy Farmers Dairy Veterinarians	Variations in awareness of prudent practices. Variations in perceived ability to implement reduced AMU. AMU deemed necessary for animal welfare	Ekakoro et al., 2018; Jones et al., 2015; Poizat et al., 2017; Kumar & Gupta 2018; Redding et al., 2014; Higham et al., 2018; Vasquez et al., 2019; Fischer et al., 2019; Speksnijder et al., 2015; Golding et al., 2019; Orpin, 2007; Scherpenzeel et al., 2016 & 2018.
Improved ability to prevent and manage mastitis and other disease while reducing AMU via improved biosecurity and herd management measures	Dairy Farmers Dairy Veterinarians	Mastitis is the most commonly reported reason for AMU in dairy cattle. Biosecurity and herd management recognised by many farmers and veterinarians as important steps to reduce AMU on farm	Jones et al., 2015; Raymond et al., 2006; Carmo et al., 2018, Ekabro et al., 2018; Fischer et al., 2019; Higham et al., 2018; Kayitsinga et al., 2017; Vaarst et al., 2003; Cattaneo et al., 2009; Speksnijder et al. 2015; Holstege et al., 2018; Kumar and Gupta, 2018
Increased resources Time and labour requirements of an intervention should be considered to ensure successful implementation	Dairy Farmers Dairy Veterinarians	Time constraints and labour burden reported as barriers to achieving reduced AMU	Friedman et al., 2007; Golding et al., 2019; Poizat et al., 2017; Scherpenzeel et al. 2016; Speksnijder et al. 2015
Increased engagement Encouraging veterinarians to take on a proactive role in promoting alternatives to antimicrobials	Dairy Veterinarians	Veterinarians are seen by many farmers as having the ability to facilitate reduced AMU.	Scherpenzeel et al., 2016; Golding et al., 2019
Encouraging farmers to utilise veterinary services and advice to reduce AMU	Dairy Farmers	Farmers do not always seek veterinary advice due to the fees associated with their services.	Friedman et al., 2007
Further research To obtain a clearer picture of the prophylactic use of antimicrobials in dairy cattle	Dairy Farmers & Veterinarians	Limited published data on the prophylactic AMU on dairy farms.	Busani et al., 2004; Redding et al., 2014; Speksnijder et al., 2015
To explore how the opinions of others may influence farmer and veterinarian decision making regarding AMU	Dairy Farmers Dairy Veterinarians	Many farmers and veterinarians are motivated by social norms within the industry.	Jones et al., 2015 Scherpenzeel et al. 2016 Scherpenzeel et al. 2018

To determine the influence farmers have on veterinarian's decision to prescribe antimicrobials and how this can be minimised	Dairy Veterinarians	Some veterinarians perceive pressure from farmers to prescribe antimicrobials and the perceived skills and knowledge of farmers can influence prescribing decisions.	Speksnijder et al. 2015; Higgins et al., 2017; Redding et al., 2013; Golding et al., 2019
To enable farmers and veterinarians to work together confidently and effectively to reduce AMU	Dairy Farmers Dairy Veterinarians	Many farmers and veterinarians are open to a more collaborative working relationship in order to achieve reduced AMU	Golding et al., 2019; Magalhaes Sant'Ana, 2017
To ensure harmonised policy and regulation relating to AMU in dairy cattle globally	Dairy Farmers Dairy Veterinarians	Many farmers and veterinarians would be accepting of harmonised policies and regulation to reduce AMU	Chauhan et al., 2018; Magalhaes Sant'Ana, 2017; Carmo et al., 2018; Speksnijder et al. 2015
To utilise behaviour change theory to determine evidence-based strategies to reduce AMU in dairy farming	Dairy Farmers Dairy Veterinarians	Behaviour change is considered difficult within dairy farming due to habitual practices associated with farming	Speksnijder et al. 2015

Comprehensiveness of reporting varied. Studies reported between 5 and 26 of the 32 COREQ checklist items; findings are summarized in Table 4.

Table 4: Overview of comprehensiveness of reporting for review studies based on Consolidated Criteria for Reporting Qualitative Research (COREQ) framework

COREQ Item	**Total studies**	**COREQ Item**	**Total studies**
Domain 1: Research team and reflexivity Personal Characteristics		Data collection 17. Interview guide	 33/35
1. Interviewer/facilitator	18/35	18. Repeat interviews	1/35
2. Credentials	2/35	19. Audio/visual recording	12/35
3. Occupation	9/35	20. Field notes	4/35
4. Gender	5/35	21. Duration	16/35
5. Experience and training	3/35	22. Data saturation	5/35
Relationship with participants		23. Transcripts returned	0/35

6. Relationship established	1/35		
7. Participant knowledge of the interviewer	3/35	**Domain 3: analysis and findings**	
8. Interviewer characteristics	2/35	Data analysis	
Domain 2: study design		24. Number of data coders	8/35
Theoretical framework		25. Description of the coding tree	9/35
		26. Derivation of themes	16/35
9. Methodological orientation and Theory	10/35	27. Software	19/35
Participant selection		28. Participant checking	0/35
10. Sampling	35/35	Reporting	
11. Method of approach	22/35	29. Quotations presented	11/35
12. Sample size	34/35	30. Data and findings consistent	33/35
13. Non-participation	4/35	31. Clarity of major themes	13/35
Setting		32. Clarity of minor themes	8/35
14. Setting of data collection	30/35	*Average no. COREQ items per study*	*11*
15. Presence of non-participants	1/35	*Minimum no. COREQ items per study*	*5*
16. Description of sample	35/35	*Maximum no. COREQ items per study*	*26*

3.3.1 Theme 1: Farmers' and Veterinarians' Knowledge and Awareness of AMR

Previous reports have suggested that a significant proportion of the farming community lacks knowledge of AMR and prudent AMU (WHO, 2015c). In this review, about a quarter of studies explored farmers' knowledge and awareness of antimicrobials and AMR, and the reported findings varied considerably. Studies of UK and Washington dairy farmers reported high levels of awareness within their study population (Raymond et al., 2006; Higham et al., 2018), but studies of South Carolina, Malaysian, Indian, and Peruvian dairy farmers reported lower levels of knowledge and awareness amongst participants (Friedman et al., 2007; Redding et al., 2014; Chauhan et al., 2018; Sadiq et al., 2018). Knowledge and awareness of AMR were higher for those farmers studied in higher-income countries; knowledge and awareness campaigns aiming to address AMR in dairy cattle should be disseminated globally and be consistent, so that all farmers have access to this information.

Recent reports highlight the need to provide livestock farmers with training in the appropriate use of antimicrobials in animals to tackle AMR (Ozturk et al., 2019). Five studies in this review explored farmer awareness of appropriate AMU, and similarly with knowledge and awareness of AMR, the reported findings varied. Of the farmers included in the studies, Tennessee dairy farmers generally perceived their AMU to be prudent (Ekakoro et al., 2018), but farmers in the United Kingdom, India, and France admitted to lacking knowledge and information about prudent AMU (Jones et al., 2015; Poizat et al., 2017; Kumar and Gupta, 2018). In India, farmers studies who had larger dairy farms were more aware of the importance of animal husbandry practices for improving AMU than those with small farms (Kumar and Gupta, 2018). Many Peruvian and Kenyan farmers who participated

lacked an understanding of antimicrobial withdrawal times (Redding et al., 2014; Higham et al., 2016). These findings suggest that prudent AMU guidance should be disseminated globally to enable farmers to engage in practices that reduce the need for antimicrobials. Because farm sizes vary globally, the ability to reach farmers may differ, and it is important to ensure that farmers receive practical guidance relevant to the scale of their operations.

Previous literature has shown that some livestock farmers do not have sufficient awareness of the severity of the problems that result from AMR (Moreno, 2014; Landfried et al., 2018). This review found 10 studies that explored this problem, and farmers' and veterinarians' awareness about the risks associated with AMR varied. Many dairy farmers who took part in these studies from South Carolina, Washington, and the UK were aware that increased AMU contributed to the development of AMR (Raymond et al., 2006; Friedman et al., 2007; Jones et al., 2015; Golding et al., 2019). Many Malaysian, Kenyan, and Peruvian dairy farmers who took part in the studies were aware that resistant bacteria could be difficult to treat and posed a threat to their animals (Redding et al., 2014; Higham et al., 2016; Sadiq et al., 2018). In India, findings of one particular study reported farmers with large dairy farms were more aware that the overuse of antibiotics increases the reservoir of AMR in the food chain than those with small farms (Kumar and Gupta, 2018). Most veterinarians who participated understood the risks posed by AMU and agreed that it is important that AMU in livestock be restricted. Veterinarians studied in the United Kingdom demonstrated good awareness and understanding of the risks posed in terms of animal-welfare threats, farm income, and productivity (Golding et al., 2019). Meanwhile, most of the Canadian veterinarians who participated in another study agreed that AMU in the dairy industry contributed to decreased antimicrobial efficacy in dairy cattle (Léger et al., 2015). In the Netherlands, almost all veterinarians (92% of the 181 veterinarians surveyed) agreed or partly agreed that veterinary AMU should be restricted to reduce AMR (Scherpenzeel et al., 2018). These findings suggest that the awareness of the risks associated with AMR is relatively high and widespread. Continuous information transfer of the risks associated with animal health because of AMU and AMR is important to ensure that all stakeholders are aware of the consequences of antimicrobial misuse.

Scepticism in the livestock sector about the contribution of agriculture to AMR has been previously identified, especially in terms of the potential links between agricultural AMU and human health risks (Morris et al., 2016; Etienne et al., 2017). In line with previous findings, this review found that awareness of the link between AMR in agriculture and humans was low (within the 20% of studies which explored this topic). Although many South Carolina and Washington dairy farmers agreed that AMR could occur in both humans and animals, they showed a lack of concern that the overuse of antimicrobials or AMR in animals could threaten farm workers (Raymond et al., 2006; Friedman et

al., 2007). Very few UK, India, or Tennessee dairy farmers perceived the threat of AMR in humans as a result of AMU or AMR in animals (Jones et al., 2015; Ekakoro et al., 2018; Kumar and Gupta, 2018). Only 2 studies explored veterinarians' awareness of the link between AMR in humans and animals. Some Dutch veterinarians were motivated to reduce their AMU for public health reasons, but others doubted a significant contribution from veterinary AMU to AMR in humans (Speksnijder et al., 2015). Most Canadian dairy veterinarians disagreed on some level that AMU in dairy cattle contributed to resistance in human medicine (Léger et al., 2015). These findings suggest that although farmers and veterinarians have an awareness of some of the potential risks associated with AMR, many believe that the overuse of antimicrobials in agriculture does not affect the development of AMR in humans. To overcome this misconception, improve understanding, and encourage more prudent AMU, evidence-based information about the links between AMU and AMR in livestock and AMR in humans should be promoted to both farmers and veterinarians.

These findings show that although some farmers and veterinarians know that AMR can occur in humans and animals, many do not perceive a risk to human health as a result of agricultural AMU. The gap between knowledge and behaviour suggests that farmers and veterinarians hold competing beliefs about what constitutes appropriate use; this can be considered a form of cognitive dissonance (Festinger, 1957) and highlights the need for increased education of farmers and veterinarians about the need for prudent AMU. Awareness campaigns should be targeted at dairy farmers and veterinarians globally to improve understanding of AMR and promote consistent, prudent AMU. Academic research should be translated to farmers and veterinarians in a relatable manner, and continuous transfer of information about AMR risk relating to livestock is needed, with an emphasis on its links to human medicine.

3.3.2 Theme 2: Determinants of farmer and veterinarian's AMU practices

Reasons for AMU in the dairy sector. Previous literature has shown mastitis to be the most frequently occurring disease in dairy cows (Ruegg, 2017) and the most prevalent reason for antimicrobial prescription in dairy cattle (DeBriyne, 2014). This review confirmed these findings as the majority of dairy farmers and veterinarians indicated that their most common reason for AMU was as a result of mastitis in the eight studies exploring reasons for AMU. The majority of veterinarians studied in Denmark, Portugal and Sweden, and dairy farmers studied in the UK, USA, Denmark and Sweden agreed that mastitis is the most common reason for AMU on dairy farms (Vaarst et al., 2003; Raymond et al., 2006; Jones et al., 2015; Kayitsinga et al., 2017; Carmo et al., 2018, Ekakoro et al., 2018; Higham et al., 2018; Fischer et al., 2019). Respiratory infections such as pneumonia (Jones et al., 2015; Ekakoro et al., 2018; Fischer et al., 2019), lameness and hoof problems were also noted as common reasons for dairy farm AMU (Raymond et al., 2006; Ekakoro et

al., 2018, Fischer et al., 2019). Whilst antimicrobials are used to treat a number of conditions in dairy cattle, AMU is linked more significantly to mastitis. In order to overcome this, education of farmers and veterinarians on the prevention and management of mastitis without or with minimal AMU is necessary including strategies such as selective dry cow therapy (SDCT), whereby cows with a low probability of an intramammary infection do not receive antibiotics (Kabera et al., 2020).

The use of antimicrobials for disease prevention in addition to therapeutic use has been argued in other veterinary contexts (Coyne et al., 2016). Three studies within this review explored prophylactic AMU. Many Italian veterinarians stated that they administered antimicrobials before the onset of mastitis (62%) more often than before the onset of respiratory diseases signs (28%) (Busani et al., 2004). Peruvian dairy farmers and Dutch veterinarians also reported some prophylactic AMU although they advised that their use was primarily therapeutic (Redding et al., 2014; Speksnijder et al., 2015). These findings suggest that prophylactic AMU is uncommon in dairy farming. However, it should be noted that very few studies within this review reported on such use and so findings may not be applicable to the wider dairy sector. It is important to note that farmers may be apprehensive to fully disclose the degree to which they prophylactically use antimicrobials as a result of bias. Future research should explore prophylactic use further to obtain a clearer idea of the level at which such use occurs in dairy cattle.

Farmer treatment choice factors. Antimicrobials play a crucial role in veterinary medicine to maintain animal health and welfare (FAO, 2016; Hudson et al., 2017) and so it is unsurprising that animal welfare has previously been highlighted as a driver of AMU in other agricultural sectors (Lhermie et al., 2019). The importance of animal welfare in deciding on AMU was confirmed within this review by three studies of dairy farmers from the UK, USA, and Denmark (Vaarst et al., 2003; Jones et al., 2015; Ekakoro et al., 2018; Golding et al., 2019). Farmers in other livestock sectors have previously reported that they have adequate knowledge of their animal's behaviour and the ability to identify abnormalities which indicate the presence of disease (Landfried et al., 2018). Within this review, previous experience and ability to accurately judge their animal's health when deciding on treatment options were reported to influence AMU decision making in four studies by many famers from Germany, the Netherlands, New Zealand and USA (Raymond et al., 2006; Swinkels et al., 2015; McDougall et al., 2017; Ekakoro et al., 2018).

Previous literature stated that farmers rely strongly on their veterinarian for advice (Lathers, 2001) and recommendations have been made that farmers should rely on knowledgeable veterinarians to make accurate treatment decisions based on credible examinations of their animals (Ruegg, 2006). The impact of veterinary advice on farmer decision making varied between the six studies which

explored the topic within this review. Farmers studied in the Netherlands, New Zealand, Peru and USA (Michigan, Minnesota, New York & Wisconsin) reported that veterinary recommendation is the most important factor in their decision making process (Zwald et al., 2004; Redding et al., 2014; Swinkels et al., 2015; McDougall et al., 2017), while less than half of the dairy farmers studied in Malaysia and Pennsylvania routinely seek veterinary advice or prescription prior to antimicrobial administration (Sawant et al., 2005; Sadiq et al., 2014).

Other factors influencing farmer AMU decision making within this review included drug attributes such as perceived efficacy of medicines, withdrawal times and cost (Redding et al., 2014; Ekakoro et al., 2018) ensuring profitability and financial safeguarding (Jones et al., 2015; Golding et al., 2019), specific cow characteristics (Vaarst et al., 2002; Vaarst et al., 2003), culture and sensitivity testing (Ekakoro et al., 2018) and recommendations of other farmers (Swinkels et al., 2015).

The variety of reported influences on farmer behaviour within this review suggests that farmer decision making is not always straightforward and depends on individual situations as well as potentially their working relationship with their veterinarian. It is important to note that within the scope of this review not all studies explored the reasoning behind farmers AMU in the same way, therefore future research should consider investigating such factors further.

Determinants of veterinarians prescribing practices. Clinical factors such as disease signs, antimicrobial susceptibility and predicted treatment outcomes have been found to motivate antimicrobial prescribing decisions in human medicine (Coenen et al., 2002, Teixeira Rodrigues et al., 2013). Many veterinarians from five studies within this review confirmed that this plays an integral part in antimicrobial prescribing in livestock with many ideally basing their treatment decision on the specific clinical situation. Prior to prescribing it is vital for many veterinarians to perform a physical examination of the animal (Redding et al., 2013; Chauhan et al., 2018; Golding et al., 2019). Understanding farm disease history and treatment response is also considered by many veterinarians (Cattaneo et al., 2009; Redding et al., 2013; McDougall et al., 2017; Golding et al., 2019).

Antimicrobial characteristics have been reported to motivate antimicrobial prescribing decisions in human medicine (Coenen et al., 2002, Teixeira Rodrigues et al., 2013). Three studies within this review reported that drug attributes influence veterinarian's decision-making. Drug efficacy, withdrawal time and ease of administration are considered by some Canadian, Dutch and UK veterinarians when prescribing antimicrobials (Léger et al., 2015; Speksnijder et al., 2015; McDougall et al., 2017). Veterinarians' perceptions of farmers knowledge and abilities were considered by UK & Peruvian veterinarians (Redding et al., 2013; Golding et al., 2019). Profit was not commonly

considered by the veterinarians within this review when deciding on treatment options, some Canadian and Dutch veterinarians felt that veterinarian profit is no longer a driver for antimicrobial prescription within the dairy sector (Léger et al., 2015; Speksnijder et al., 2015).

Veterinarians' perceptions of their client's willingness or ability to pay for treatment and how compliant they would be in administering the treatments, have been found to influence veterinary prescribing outside of the dairy sector (Mateus et al., 2014). Within this review it was reported by veterinarians in three studies that farmers often influence their decision making. Some veterinarians in the UK and Kenyan admitted that they sometimes fulfil treatment requests of farmers to avoid upsetting them (Higham et al., 2016; Higgins et al., 2017) and some Canadian veterinarians dispensed antimicrobials over the counter to regular clients more often (Léger et al., 2015).

It should be noted that within this review studies exploring the decision making of veterinarians for prescribing antimicrobials within the dairy sector were scarce. The most common influencer of veterinarian's decision making reported within this review was the individual clinical situation and perceptions of the farmer. Future research should explore how veterinarians can build better relationships with their clients so that they can focus on the individual clinical situation as opposed to concerns of upsetting farmers.

3.3.3 Theme 3: Barriers and facilitators to reduced antimicrobial use in the dairy sector

Barriers to reduced AMU. Deciding whether to continue or withdraw antimicrobial treatment was found to be problematic for many farmers and veterinarians within this review, due to the unpredictable nature of disease and the potential cost of disease returning when antimicrobials are discontinued. Such concerns are also common within pig production (Sheehan et al., 2013). Economic constraints such as the cost of disease and changes in farm structures to achieve reduced AMU were reported within six studies as limitations in Dutch, Swedish, Irish, UK and US studies (Raymond et al., 2006; Friedman et al., 2007; Speksnijder et al., 2015; Magalhaes Sant'Ana et al., 2017; Fischer et al., 2019; Golding et al., 2019). Some farmers in the USA suggested that veterinarians are not always consulted for AMU advice due to their fees (Friedman et al., 2007) while others reported they have previously been concerned that milk production would reduce if antibiotics were not used for dry-cow treatment (Raymond et al., 2006). Prophylactic AMU was considered necessary by some Dutch veterinarians, arguing that if certain infections were not prevented, they could result in increased mortality and financial loss (Speksnijder et al. 2015). These findings suggest that many farmers and veterinarians are concerned that reduced AMU may come with economic risks. Further research should focus on how economic risks of reducing AMU can be minimised.

Previous findings suggest that having a productive farm and taking good care of their animals are important to farmers and central to how they conceptualise a good farmer (Wilkie, 2005; Bock et al., 2007, Ellis, 2014, Shortall et al., 2018). This was confirmed by six studies within this review, farmers and veterinarians reported animal welfare as a barrier to reducing AMU. There was concern amongst farmers and veterinarians in the UK that reductions could inhibit their ability to treat sick animals and maintain animal welfare (Golding et al., 2019). Farmers studied in France and the UK feared that no antibiotic cover would lead to severe mastitis and death (Orpin, 2007; Poizat et al., 2017). Dutch farmers and veterinarians were unsure whether a cow would recover without antimicrobials (Scherpenzeel et al. 2016; Scherpenzeel et al. 2018) and many Dutch veterinarians reported it is their duty to treat diseased animals for reasons of animal welfare, regardless of the issue of AMR (Speksnijder et al. 2015). Despite these findings, research in the UK dairy sector found that ceasing the use of the highest priority critically important antimicrobials can occur while maintaining herd health and farm productivity (Turner et al., 2018). These findings highlight the responsibility to animal welfare felt by farmers and veterinarians; thus, they feel that antimicrobials are essential to preserve animal welfare and productivity. Further education on the efficacy of alternative practices to reduce AMU, may build confidence in their ability to maintain animal welfare while reducing AMU.

Time constraints and labour burden were commonly noted as barriers to reduced AMU within five studies (Friedman et al., 2007; Speksnijder et al. 2015; Scherpenzeel et al. 2016; Poizat et al., 2017; Golding et al., 2019). Some South Carolina farmers reported not having time to wait for a veterinarian to make a farm visit as they need to make quick judgements to avoid infection spread (Friedman et al., 2007). Selective antimicrobial treatments were seen by many Dutch and French farmers as requiring additional work (Scherpenzeel et al. 2016; Poizat et al., 2017) and some Dutch veterinarians agreed that such treatment is generally more labour intensive than mass medication and so it can be difficult to convince farmers to adopt such practices (Speksnijder et al. 2015). Despite a desire to make greater use of diagnostic testing and an appreciation for its importance to reduce AMU, many veterinarians felt that it is often impractical due to delays in obtaining results (DeBriyne et al., 2013; Coyne et al., 2016; Golding et al., 2019) and is sometimes only used by Dutch, Indian and UK veterinarians when initial treatments are unsuccessful (Speksnijder et al., 2015; McDougall et al., 2017; Chauhan et al., 2018). These findings suggest that when considering interventions and promoting reduced AMU, labour and time requirements should be considered to ensure successful implementation.

Pressure from farmers to prescribe antimicrobials is often highlighted in studies investigating the prescribing behaviours of veterinarians in a range of veterinary contexts (DeBriyne et al., 2013,

Gibbons et al., 2013; McIntosh & Dean, 2015; Coyne et al., 2016). This was confirmed in this review with many veterinarians in two studies reporting that pressure from farmers can limit their efforts to reduce AMU. Some Dutch veterinarians felt pressure to prescribe antimicrobials and sometimes have difficulty persuading farmers to reduce AMU (Speksnijder et al. 2015). Within this review some UK veterinarians reported that it is sometimes difficult to prioritize responsible AMU due to conflicts of interest and fear of upsetting farmers (Higgins et al., 2017). Findings in other veterinary contexts have shown that some veterinarians are more influenced by social expectations than scientific reasoning, acting upon client pressures to prescribe even when they felt antimicrobials were unnecessary. This prescribing behaviour has also been observed with human antibiotic prescribing practices (Paredes et al., 1996; Tonkin-Crine et al., 2011; Broom et al., 2014; Hockenhull et al., 2017; Smith et al., 2018). Veterinarians have previously been advised to adopt new communication styles and overcome the assumptions they may have about farmers in order to ensure engagement with them on disease prevention and antimicrobial stewardship (Jansen et al., 2010). Although perceptions of farmers were highlighted by many veterinarians within this review as influencing prescribing practices and often limiting their efforts to reduce AMU, not many explicitly identified this as a barrier to reducing AMU. Despite similar findings being reported in other veterinary contexts regarding farmer pressure as a barrier to reduced AMU, such literature in the context of dairy farming is limited and so may be worth focus from future research.

Some Dutch veterinarians noted that high on farm AMU may be due to insufficient skills of farmers in terms of disease detection and recommended practices (Speksnijder et al. 2015). Irish veterinarians acknowledged that farmers generally have little awareness of the connection between their husbandry practices and AMR in human medicine, suggesting that until this is understood, farmer behaviour will not change (Magalhaes Sant'Ana et al., 2017). Despite this being highlighted as a barrier to reduced AMU within this review it cannot be assumed as the view of all veterinarians due to the small number of studies exploring veterinarians' perceptions of farmers skills and knowledge as a barrier to reduced AMU. Future research is needed to determine whether this is a common attitude of veterinarians dealing with dairy farmers.

Other barriers reported included social constraints (Fischer et al., 2019), industry pressure (Golding et al., 2019), low risk perception (Higgins et al., 2017), scepticism of antimicrobial alternatives (Vaarst et al., 2003) and the fact that antimicrobial treatments are effective and convenient (Poizat et al., 2017). These findings were not as commonly reported however should still be given consideration in attempts to reduce AMU and perhaps deserve attention in future research.

These findings show farmers and veterinarians consider numerous factors to be barriers to reducing their AMU in dairy cattle. Economic constraints, animal welfare, structural limitations (time constraints and labour requirements), individual attitudes to AMR, pressure felt by veterinarians from farmers as well as veterinarians' perceptions of farmers are commonly reported barriers to reduced AMU. To overcome the main barriers identified by this review future research should explore how AMU can be reduced with minimal economic risk, promoting the efficacy of alternative practices while maintaining animal welfare and how pressure felt by veterinarians from farmers can be reduced. From these findings it is recommended that interventions aimed at reducing AMU consider the labour and time requirements, as well as providing the skills and knowledge necessary to efficiently achieve reductions.

Facilitators of reduced AMU. Previous research suggests herd management and improved biosecurity as a cost effective and feasible approach to disease prevention, and alternative to reliance on routine AMU (Postma et al., 2015; Rojo-Gimeno et al., 2016). Improved biosecurity and management practices have been associated with reduced AMU in pig production (Lannen et al., 2013; Arnold et al., 2016; Postma et al., 2016). On farm management measures and disease prevention controls were welcomed by many farmers and veterinarians from eight studies within this review as facilitators of reduced AMU. Disease prevention with consistent health management practices was considered important by veterinarians studied in Denmark, Portugal, Switzerland, and the USA (Cattaneo et al., 2009; Speksnijder et al. 2015; Carmo et al., 2018). Similarly, many Indian, Swedish, Dutch and American dairy farmers agreed that practices such as proper nutrition, housing, breeding and infection control were important to reduce AMU (Ekakoro et al., 2018; Holstege et al., 2018; Kumar and Gupta, 2018; Fischer et al., 2019). Vaccinations are also seen by some farmers and veterinarians as a method of reducing AMU (Cattaneo et al., 2009, Ekakoro et al., 2018) and it is seen as a cost-effective strategy to control the spread of AMR by Indian farmers (Kumar and Gupta, 2018). On farm diagnostic testing is considered a facilitator of reduced AMU by Irish veterinarians (Magalhaes Sant'Ana et al., 2017) and some Tennessee dairy farmers reported that such testing has previously led to a reduction in AMU (Ekakoro et al., 2018). Correct diagnostic processes and early disease detection are considered important by some US dairy farmers and Dutch veterinarians to avoid unnecessary AMU (Speksnijder et al. 2015; Ekakoro et al., 2018). This suggests that many farmers and veterinarians within this review and potentially outside its scope, see improved herd management and biosecurity measures as important steps to reduce AMU while maintaining productivity and animal welfare and should be promoted to encourage behaviour change.

Increasing farmers' ability to implement alternative practices has been reported to enhance their efficiency in reducing AMU (Visschers et al., 2016b). Programs aimed at increasing awareness of

AMU and AMR are hypothesised to contribute to a reduction in agricultural antimicrobial sales (Carmo et al., 2017). Relevant and targeted information is considered vital when aiming to alter behaviour and for the targeted population to pay attention to information, it is important that education is tailored to their needs and knowledge (Kreuter et al., 1999). Within this review, training and education was considered important by farmers and veterinarians to facilitate reduced AMU within five studies. Some UK veterinarians felt that farmers having the skills to implement selective therapy facilitates reduced AMU (Higgins et al., 2017) and the need for additional farmer training on infection prevention and control was supported by some Tennessee dairy farmers to reduce AMU (Ekakoro et al., 2018). Many veterinarians studied supported increased veterinary education on prudent AMU and alternative practices to promote their use amongst clients and facilitate reduced AMU (Magalhaes Sant'Ana et al., 2017; Poizat et al., 2017; Carmo et al., 2018). The review findings suggest that education of farmers and veterinarians is fundamental in the fight against imprudent AMU in dairy cattle. Combined with the desire for increased knowledge relating to AMU and AMR, expressed by farmers within this review, this highlights its importance and potential to help facilitate reduced AMU.

The potential economic rewards of profitability and reduced costs have been reported as the most important driver of AMU behaviour change in pig farming (Visscher et al., 2015). Some Dutch veterinarians were concerned that higher tariffs for their services would decrease farmers' motivation to consult them and so they consider low tariffs essential for animal health and appropriate AMU (Speksnijder et al. 2015). To reduce farm AMU, it has been suggested that farmers and veterinarians should be incentivised to make reduced AMU more salient in their day-to-day operations, perhaps by using financial incentives such as those recently used in the English national health service (Islam et al., 2018). Some Indian veterinarians were concerned by the lack of incentive for farmers withholding antimicrobial treated milk, stating that withholding should be incentivised to prevent antimicrobial tainted milk entering the food chain (Chauhan et al., 2018). Within this review such financial facilitators to reduced AMU were confirmed by farmers and veterinarians. In the Netherlands, some noted 'financial consequences' as one of the most positive aspects of reducing AMU (Scherpenzeel et al. 2016) and some French veterinarians stated that they have highlighted the cost benefit of alternative medicines to farmers to promote reduced AMU (Poizat et al., 2017). These findings suggest that many farmers and veterinarians see economic rewards for reducing AMU as having the potential to facilitate and encourage behaviour change. As economic burden has been highlighted within this review as a barrier to reduce AMU, promoting the evidence that farms can remain productive and profitable while reducing AMU is necessary.

It has been reported that there may be scope for veterinarians to take on a more proactive role in promoting preventative medicine to farmers, in order to reduce AMU (Higgins et al., 2013). Within this review some farmers highlighted the role their veterinarians could play in reducing AMU. Dutch farmers felt that veterinarians could help facilitate change as they are their main advisors and encouragers of reduced AMU (Scherpenzeel et al. 2016) and UK farmers also expressed a desire for guidance from their veterinarians to reduce AMU due to the support and motivation they provide (Golding et al., 2019). These findings, although limited within the scope of this review, coupled with many farmers reporting the key role of veterinarians in their decision making, suggests that veterinarians can play a pivotal role in promoting AMU reduction.

Improved policy and regulation of AMU in livestock was deemed necessary by Irish and Indian veterinarians within this review to reduce AMU (Magalhaes Sant'Ana et al., 2017; Chauhan et al., 2018). Some veterinarians from Denmark, Portugal and Switzerland also advised that mandatory interventions applied by national or international authorities have appeared to work best in reducing AMU in the past (Carmo et al., 2018) and many Dutch veterinarians felt that policies to reduce AMU should be equal in all countries to maintain a fair, competitive market and prevent illegal antimicrobial trade (Speksnijder et al. 2015). UK farmers reported that they see government and industry bodies as having the resources and expertise to conduct research and produce evidence-based guidelines to facilitate reduced AMU (Golding et al., 2019). This suggests that farmers and veterinarians would be accepting of evidenced based policies and regulations being introduced or revised to reduce AMU. It is suggested that many veterinarians and farmers would be open to regulations being harmonised in all countries, but this would need to be a potential focus for future research due to the limited findings within this review.

These findings show that numerous factors are perceived by farmers and veterinarians as having the potential to facilitate reduced AMU. From these findings future research recommendations include the promotion of herd health management and biosecurity measures, coupled with improved education of farmers and veterinarians on alternative practices to increase their confidence in their ability to reduce AMU. Promotion of evidence that farms can remain productive and profitable with reduced AMU is necessary to overcome this uncertainty which exists amongst some farmers and veterinarians. Findings suggest that veterinarians can play a pivotal role in promoting reduced AMU and that harmonisation of regulations and policy regarding AMU should be considered by future research as ways in which AMU in the dairy industry can be improved.

3.3.4 Theme 4: Farmer and veterinarians' responsibility to AMR and desire to reduce AMU

Prudent use of antimicrobials in livestock is reported to be the responsibility of veterinarians and farmers and so both need to be aware of the impact their AMU can have (Reyher et al., 2017).

Within this review, 60% of studies reported on farmer and veterinarians perceived responsibility to AMR. Some UK farmers expressed ownership for improving AMR (Golding et al., 2019) while of the Malaysian farmers studied, their role in tackling AMR was perceived as more important by those with a larger herd size (Sadiq et al., 2018). Dairy farmers studied in Germany and the Netherlands felt that meat-producing farmers were responsible for agricultural AMR (Swinkels et al., 2015) and some UK and Malaysian famers considered veterinarians responsible for managing the emergence of AMR (McDougall et al., 2017; Sadiq et al., 2018). Research has found that this external attribution of responsibility to others is a major barrier to behavioural change and must be understood, accounted for and managed in policy development (Ruegg et al., 2017). These findings suggest that not all farmers recognise the role they play in the development and spread of AMR.

Previous literature advised that enabling behavioural change requires farmers and veterinarians to perceive their own personal roles and actions as efficacious and important in relation to AMR (Fishbein & Cappella, 2006). Within this review many UK and Irish veterinarians acknowledged their responsibility to prescribe appropriately and have a sense of ownership in promoting reduced AMU (Magalhaes Sant'Ana et al., 2017; Golding et al., 2019). Some US veterinarians believe that many individuals including themselves contribute to AMR (Cattaneo et al., 2009) and while many Dutch veterinarians appeared to be motivated to reduce veterinary AMU for public health reasons, others doubted the contribution their use has on human health (Speksnijder et al. 2015). These findings suggest that although some veterinarians perceive their role in AMR as important, further education to consider their own practices as important to mitigate the spread of AMR is needed.

Many Dutch, UK and US farmers agreed that it is important to reduce AMU (Jones et al., 2015; Scherpenzeel et al. 2016; Kayitsinga et al., 2017). Some UK farmers felt that people in the industry would respect them for reducing their AMU (Jones et al., 2015) and Dutch farmers felt they could still be a good farmer while using less antimicrobials (Scherpenzeel et al. 2016). Some Dutch veterinarians also agreed that it is important to restrict livestock AMU, many trusting that they can be a good veterinarian and farmers can still be good farmers with less AMU (Scherpenzeel et al. 2018). These findings suggest that farmers and veterinarians are motivated by being considered "good" by their peers and industry colleagues by conforming to the social norms of the industry, which may facilitate reduced AMU. Within the scope of this review, few studies were found that focused on the opinion of others as a facilitator to reduced AMU and so may be considered by future research.

Previous literature stated that veterinarians and farmers are not always aware of the public health risks associated with extensive agricultural AMU and so do not always feel responsible for the

problematic outcomes, lowering their motivation to change their behaviour (Coyne et al., 2016; Ritter et al., 2017; Visschers et al., 2016a). The perceived ability to reduce AMU varied amongst farmers within this review. Many UK and US farmers felt they had the ability to reduce AMU (Higham et al., 2018; Vasquez et al., 2019) and some Swedish farmers admitted they could make more effort to reduce AMU (Fischer et al., 2019). Dutch and French farmers felt reducing their AMU could be difficult and despite many veterinarians feeling a responsibility to tackle AMR, some still consider prophylactic AMU necessary to safeguard animal welfare (Speksnijder et al. 2015; Poizat et al., 2017). These findings show that the perceived ability of farmers and veterinarians to reduce AMU is varied, combined with the concern and uncertainty associated with reduced AMU reported within this review, reinforces the importance of education on alternative practices to enable farmers and veterinarians to confidently reduce their AMU.

Within this review dairy farmers in the UK and USA reported positive intentions towards prudent AMU (Jones et al., 2015; Vasquez et al., 2019), while farmers and veterinarians in Switzerland supported the proposal of voluntary programs to reduce AMU (Van den Borne et al., 2017). Another study of Dutch veterinarians also reported a positive attitude towards policy change to reduce AMU (Scherpenzeel et al. 2018). Previous literature recommended that shared responsibility between farmers and veterinarians may help behaviour change as there is evidence that farmers intentions to change is reinforced by mutual support from their major referents which includes veterinarians and other advisors (Ellis-Iversen et al., 2010). These findings suggest that the intentions of many farmers and veterinarians towards reducing AMU within the dairy sector may be primarily positive. This could be beneficial for the introduction of policy and programs designed to reduce AMU. Further research is however necessary to reinforce this finding.

Based on these findings it is recommended that there is a focus on improving the education of farmers and veterinarians so that they recognise the role their AMU practices can have on AMR in both veterinary and human medicine, in order to heighten the responsibility they feel towards the issue. There is also scope for research into how peers and colleagues of farmers and veterinarians **within the dairy industry can act as motivators to their desire to reduce AMU.**

3.3.4 Theme 5: The importance of the farmer-veterinarian relationship dynamic in reducing AMU

Just over 50% of the studies included in this review reported on the farmer-veterinarian relationship and the role it may play in AMU within the dairy sector.

Communication and information transfer between farmers and veterinarians. It has been reported by several studies that veterinarians are farmers preferred information source for general farming

practices (Garforth et al., 2013) and AMU guidance (Visschers et al., 2015, Visschers et al., 2016a). Within this review the relationship and communication with veterinarians were valued highly by many Dutch, German, UK and US farmers, with veterinarians often identified as their most credible, reliable and influential AMU and AMR information sources (Friedman et al., 2007; Jones et al., 2015; Swinkels et al., 2015; Kramer et al., 2017; Golding et al., 2019). Some Dutch, German and US farmers consider veterinarians to be the most important information source for mastitis (Swinkels et al., 2015; Kayitsinga et al., 2019) and veterinary recommendation and advice is considered by some Peruvian, Dutch and UK farmers as their most important decision-making factor (Redding et al., 2014; Scherpenzeel et al. 2016; McDougall et al., 2017). Some Swedish farmers highlighted the importance of a good relationship with their veterinarian, despite this many reported that they only call on them when they are sure they cannot cure the animal themselves (Fischer et al., 2019). Many Peruvian, UK and US famers do not always seek the advice of their veterinarian before administering antimicrobials (Redding et al., 2014; Jones et al., 2015; Sawant et al., 2007). It could be suggested from these findings that despite many farmers perceiving their veterinarians as credible and important information sources they do not always seek their advice which may be linked to the findings within this review that some farmers feel veterinary fees are too expensive.

Veterinarians' communication experiences with farmers varied within this review. Many Indian veterinarians reported that by the time a farmer seeks their help they have already tried many unsuccessful treatment strategies (Chauhan et al., 2018). Despite this many Dutch veterinarians reported that providing advice to farmers is increasingly becoming part of their daily work (Speksnijder et al. 2015). One-on-one meetings between veterinarians and farmers are considered by many US veterinarians as the most effective way to educate farmers on AMR (Cattaneo et al., 2009). Despite a desire to educate farmers, it was reported that some Canadian veterinarians are more likely to dispense antimicrobials over the counter to clients they have regular contact with as opposed to those who they rarely meet with (Léger et al., 2015). These findings suggest that many veterinarians have a desire to provide advice and education to farmers however some acknowledge that they are not always farmer's first point of contact. It could be suggested that veterinarians have the ability to guide farmers in reducing their AMU and encouraging them to utilise veterinary services more frequently may help tackle antimicrobial misuse.

Farmer and veterinarians' perceptions of each other. Previous literature highlighted the need to communicate the importance of restrictive AMU through information channels which farmers perceive to be trustworthy (Ritter et al., 2017). Within this review many Swedish and UK farmers trusted their veterinarians' AMU information and recommendations (Ekakoro et al., 2018; Fischer et al., 2019; Golding et al., 2019). Some Swedish farmers expressed a desire for a trust-based dialog

with their veterinarian, they want their veterinarians to trust in their farming competence and abilities as much as farmers trust in their medical expertise (Fischer et al., 2019). Veterinarians' perceptions of their client's compliance have been reported previously as a common non-clinical factor influencing antimicrobial prescribing decisions, this influence has also been reported in human medicine (Teixeira Rodrigues et al., 2013; Coyne et al., 2016). Some Peruvian veterinarians admitted that their perception of farmers' education level and ability to understand drug attributes and pathogens sometimes influenced their prescribing (Redding et al., 2013). Although many UK veterinarians felt farmers follow their treatment advice some advised that if they were concerned a farmer would not adhere, they would account for this when prescribing (Golding et al., 2019). Dutch veterinarians reported that as they are only able to make recommendations to prevent disease with no way of enforcing it, they often experienced feelings of frustration with farmers because when a farmer did not follow their advice, they were again confronted with sick animals (Speksnijder et al. 2015). Existing literature advises that generally, veterinarians are perceived as trustworthy referents for farmers therefore it is postulated that they act as the main information source on prudent AMU (Ellis-Iversen et al., 2010; Speksnijder & Wagenaar, 2018). These review findings suggest that farmers trust in their veterinarians for advice however some may desire that the trust is reciprocated by the veterinarians. This highlights the importance of two-way trust between farmers and veterinarians and future research to increase this could improve their relationship and AMU practices.

Within this review some UK veterinarians perceived differences in farmers' personalities, occasionally influencing their prescribing decision and willingness to raise the topic of antimicrobial stewardship. They sometimes prescribed antimicrobials to prevent awkward situations noting that it takes time to develop effective relationships with farmers (Higgins et al., 2017; Golding et al., 2019). Dutch and UK veterinarians were sensitive to the financial pressures they feel farmers face, leaving them limited in their ability to help and hesitant to increase their service tariffs (Speksnijder et al. 2015; Golding et al., 2019). This suggests that not all farmers are perceived equally by veterinarians and such perceptions depend on the relationship they have with their clients. Farmers and veterinarians' perceptions of each other may be contributing to difficulties in reducing AMU and so future research should explore this further.

Many Dutch veterinarians perceived that farmers are accustomed to raising their animals with antibiotics (Speksnijder et al., 2015), and client habits were noted by Peruvian veterinarians as a determinant of prescribing (Redding et al., 2013). Some Indian and UK veterinarians perceived farmers as reluctant to change their behaviour and considered changing farmers AMU a challenge (Chauhan et al., 2018; Golding et al., 2019; Higgins et al., 2019). Relatively new commercial dairy

farmers were found by some Indian veterinarians to be more open to modifying practices (Chauhan et al., 2018) and many UK veterinarians believe that a key part of their role is to better educate farmers and believe that engaging with a farmer and understanding their needs can impact on farmer behaviour (Golding et al., 2019). This suggests that according to many veterinarians, achieving behaviour change amongst dairy farmers is difficult. Future research should utilise behaviour change theory in an effort to determine evidence-based interventions and strategies which can be aimed at both farmers and veterinarians to achieve reduced AMU.

Collaboration between veterinarians and farmers. Research suggests that the reduction of AMU requires participation from all stakeholders responsible for administering antimicrobials including veterinarians, producers, and animal handlers (Salisbury et al., 2002). Better animal health outcomes may be achieved by collating expert opinions, the use of multi-disciplinary teams in human healthcare has been shown to improve patient outcomes (Hickman et al., 2015, Mudge et al., 2006). Within this review, encouraging collaborative work between veterinarians and farmers was considered an important strategy for improving antimicrobial stewardship by some UK farmers and veterinarians (Golding et al., 2019). A collective responsibility amongst stakeholders was also seen by Irish veterinarians as having the potential benefit of limiting individual stakeholder ownership of the AMR problem (Magalhaes Sant'Ana, 2017). Despite a desire to work collectively, some UK farmers and veterinarians demonstrated frustrations towards other stakeholders and colleagues, as they felt that their behaviour is sub optimal while others felt their own antimicrobial stewardship efforts are undermined by other stakeholders and differing practices globally (Golding et al., 2019). This other blaming (placing the blame for increased AMR and imprudent AMU on other parties) has been observed previously by stakeholders in both human and veterinary medicine (Labi et al., 2018; Nicholson et al., 2018). It has been suggested that at an individual level approach, increasing the use of inclusive, one health stewardship initiatives which target individual knowledge and motivations may overcome other blaming as both veterinarians and farmers can feel blamed and stigmatized by others for AMR (Fynbo & Jensen, 2018; Johnson et al., 2018). Despite the authors awareness that tackling AMR is a One Health priority encompassing a multisectoral approach (FAO/OIE/WHO, 2017) only the practices and opinions of dairy farmers and veterinarians are considered within the scope of this review. These findings suggest that farmers and veterinarians may be open to more collaborative working. It should be considered however that the relationship between farmers and veterinarians and its impact on AMU is not heavily focused on by many of the studies within this review and further research is needed to confirm findings.

Some Danish farmers admitted that although their veterinarians would like closer collaboration, their financial situation would not allow for increased veterinary services (Vaarst et al., 2003) while

some Dutch veterinarians also acknowledged that low tariffs for veterinary services are needed to encourage farmers to utilize their services (Speksnijder et al. 2015). Evidence suggests that collaboration between farmers and veterinarians can be beneficial in developing antimicrobial stewardship plans on farms (Van Dijk et al., 2017) and drawing on a social identity approach could increase communication and collaboration between the groups (Jetten et al., 2017). Promoting the importance of a common fate can strengthen the shared social identity of stakeholders, and drive co-operation to achieving shared goals (Gaertner et al., 1993, Turner et al., 1994). Within this review farmers and veterinarians have identified each other as influencers of their decision-making processes and as having the ability to limit and facilitate reduced AMU. These findings make it credible that future research should focus on enabling farmers and veterinarians to work together confidently and effectively to achieve their common goal of reduced AMU on dairy farms.

This research has found that communication, individual perceptions, and trust in one another contribute to the working relationship between farmers and veterinarians. Certain aspects of these relationships have been highlighted by some as having the potential to limit or facilitate reduced AMU. Future research should aim to promote more frequent utilisation of veterinary services by farmers. Attempts to build the trust farmers and veterinarians have in one another is recommended in order to strengthen their relationships by overcoming inaccurate perceptions they may have of each other. Habits were highlighted as a potential reason why farmers do not always consult veterinarians for advice and so future research applying behaviour change theory to farmer and veterinarian behaviour is suggested to help overcome behavioural habits and result in reduced AMU. Overall, it is suggested that future research into the relationship between farmers and veterinarians is necessary in order to highlight areas which can be targeted to strengthen their relationships and promote collaboration to enable them to work together effectively to reduce AMU.

3.4 Strengths & Limitations

This research had a number of strengths and limitations. This review for the first time, systematically combined the existing literature exploring dairy farmers' and veterinarians' knowledge and awareness of AMR as well as their attitudes towards and perceptions of their AMU. This has extended previous research findings by summarising and comparing the literature from a broad range of study designs (interviews, surveys, focus groups), synthesised their primary findings and reviewed evidence supporting the findings. This review has identified potential links between previous study findings, providing scope for further research and potential avenues for promoting reduced AMU within the dairy sector. Despite the reasonable number of studies used in this review (n=35), almost all were conducted in developed countries limiting the generalizability of the results on a global scale. The findings of the majority of studies were typically self-reported and so caution

should be noted with regard to social desirability of the findings. The review has combined studies carried out over a broad period of time and so data reported by some of the studies may not necessarily reflect the current practices, attitudes, knowledge, and perceptions of participants. Additionally, care should be taken not to generalise the findings of this review, the suggestions presented are based on the farmers and veterinarians who participated in the individual studies within this review. Therefore, findings may not be representative of the entire dairy farmer or veterinarian populations in the particular countries in which the studies were conducted or on a wider global scale.

3.5 Recommendations for future research

This review has identified gaps and scarcities in previous research investigating drivers of AMU within dairy cattle. While many reasons for farmer's AMU have been highlighted within this review, some factors although quoted less frequently may provide a deeper insight into the motives behind farmer's AMU. The impact of herd size on farmer's perceptions of their AMU practices and its contribution to AMR remains relatively unknown and so further research in this area may provide a better indication as to how best to promote behaviour change with specific farming groups. There is a need for further research investigating the relationship dynamic between farmers and veterinarians and how it can be enhanced to implement reduced AMU on dairy farms. The perceptions farmers and veterinarians have of one another, in addition to the trust they have in each other remains relatively unexplored and may provide key insights into just how much this relationship may influence on farm AMU. A deeper understanding of this relationship may help facilitate a collaborative effort between farmers and veterinarians to tackle the global issue of AMR by reducing their use of antimicrobials in dairy cattle.

3.6 Conclusion

The knowledge, awareness and perceptions of dairy farmers and veterinarians regarding AMU and AMR varied between studies. Awareness of prudent AMU practices does not appear to be uniform amongst farmers and veterinarians within the dairy farming industry globally. Increasing awareness of AMR may increase farmers and veterinarians perceived individual responsibility to reducing their AMU to tackle AMR. Many factors determine the decision to use antimicrobials on dairy farms of both farmers and veterinarians which include animal welfare, time constraints and labour requirements. Addressing the perceived barriers to reducing AMU may alter farmers' and veterinarians' decision-making and education on antimicrobial alternatives may increase their perceived ability to reduce their AMU. The relationship between farmers and veterinarians and their perceptions of each other can be considered as both a barrier and a facilitator to prudent AMU on dairy farms depending on their perceived relationship dynamic. As a trusted and valuable

information source for many farmers, veterinarians can play a vital role in educating farmers on AMR and promoting antimicrobial alternatives to reduce on farm AMU. By altering their perception of their clients, veterinarians may be able to act more successfully as antimicrobial stewards to reduce on farm AMU, while maintaining a good relationship with farmers. Many farmers and veterinarians may be open to collaboration with each other in order to achieve prudent AMU and encouraging collaboration between these two key stakeholders is expected to create a shared responsibility to tackling their common goal of reducing AMU within the dairy sector. Behaviour change theory should be applied to investigations of dairy farmer and veterinarians AMU behaviours in order to effectively overcome barriers and elicit behaviour change to achieve reduced AMU.

3.7 Chapter 3 summary

Chapter 3 provided an overview of the current literature on dairy farmer and veterinarians knowledge, attitudes and perceptions of AMR and AMU. Awareness of responsible AMU practices were found to vary amongst dairy farmers and veterinarians globally and dependent on the size of farms. Dairy farmers and veterinarians perceived responsibility towards AMR may increase if their awareness of the threat AMR poses is improved. Animal welfare, time constraint and labour requirements impact the decision making of farmers and veterinarians when deciding to use antimicrobials on dairy farms. Addressing the barriers perceived by dairy farmers and veterinarians as preventing them from using antimicrobials responsibly may improve their perceived ability to reduce their antimicrobial use. Veterinarians are a trusted information source for farmers and so can play a pivotal role in encouraging responsible AMU and promoting alternative practices on dairy farms. Encouraging collaboration between dairy farmers and their veterinarians could create a shared responsibility for their common goal of achieving responsible AMU on dairy farms and help tackle AMR. Further research of dairy farmers and veterinarians AMU behaviours and attitudes towards responsible AMU, coupled with the application of behaviour change theory is recommended to overcome barriers and promote responsible AMU on dairy farms.

4. Chapter 4: Factors influencing dairy farmers' antimicrobial use: An application of the COM-B model (*study 1*)

Study 1: Abstract

Background: In dairy farming, mastitis treatment is the most common reason for antimicrobial use. The overuse or misuse antimicrobials in agriculture has been associated with the development and spread of antimicrobial resistance (AMR). Traditionally, blanket antimicrobial use in which all cows receive treatment, was used prophylactically to prevent, and manage disease spread. In recent years there has been a move towards more selective use of antimicrobials in which only clinically infected cows are treated with antibiotics for example. Objectives: This study aimed to explore farmer attitudes towards antimicrobial use (AMU), using the COM-B model as a framework, to identify predictors of using antimicrobials more selectively and suggest interventions to encourage its uptake. Results: Participant farmers (n=240) were surveyed online between March and July 2021. Five items were found to be significant predictors of farmers having stopped blanket antibiotic use: (1) having lower knowledge of AMR, (2) greater awareness of AMR and AMU (Capability), (3) feeling social pressure to reduce AMU (Opportunity) and having (4) greater professional identity and (5) positive emotions associated with stopping blanket use of antibiotics (Motivation). Binary logistic regression found these five factors explained between 22% and 34.1% of the variance in making changes to blanket antibiotic use practices and correctly classified 85% of cases. Additionally, objective knowledge was not correlated with current positive antibiotic practices and farmers often perceived their antibiotic practices as more responsible than they actually were. Conclusions: A multifaceted approach, encompassing each of the predictors highlighted should be taken to encourage farmer behaviour change in relation to stopping blanket antibiotic use. Additionally, as farmers' perceptions of their own behaviours may not align with their actual practices, awareness raising of what constitutes "responsible" behaviour should be targeted at dairy farmers to motivate them to act and adopt more responsible antimicrobial use practices.

4.1 Introduction

The systematic review of previous research (chapter 3) into the knowledge, attitudes, perceptions and behaviours of dairy farmers and veterinarians relating to AMU and AMR recommended increased knowledge, skill development, improved resources and engagement with veterinarians as having the potential to elicit appropriate behaviour change and reduced AMU in dairy cattle.

It is hypothesised that AMU behaviour can be predicted using the COM-B model components (COM-B model explained fully in section 2.3.2) and that increased knowledge of antibiotic resistance and prudent AMU will correlate with more responsible current behaviours relating to AMU.

Based on the systematic review findings and the COM-B model, this chapter utilises an online survey to assesses the current behaviours, capability, opportunity, and motivation of dairy farmers on the Island of Ireland in relation to on farm AMU and AMR. Further, it determines farmers' perceptions of their current AMU behaviours and whether or not knowledge about AMU correlated with responsible behaviour.

Finally, this chapter aimed to determine which COM-B variables predict the likelihood of farmers having made behavioural changes to stop blanket use of antimicrobials and from this what intervention functions are likely to be successful in reducing the use of antibiotics on dairy farms. The findings will help inform policy development and assist with the implementation of evidence-based behaviour change interventions to help tackle AMR on dairy farms following evaluation with dairy stakeholders (chapter 6).

4.2 Method

The survey utilised within this chapter was conducted in collaboration with a Safefood project in which similar research was being conducted with farmers across various livestock sectors which included dairy cattle, beef cattle, sheep and pig farmers. Members of the research team at Teagasc Mellows campus assisted with survey design and participant recruitment. To achieve the aims of this thesis, the PhD student amended the survey questions where necessary and included only the survey data obtained from farmers whose livestock consisted primarily of dairy cattle for data analysis.

4.2.1 Ethics and participant recruitment

The survey was conducted in line with guidelines set out by the Declaration of Helsinki. Study procedures involving participants were approved by the Faculty of Medicine, Health and Life Sciences Research Ethics Committee at Queen's University Belfast (MHL 20_123). All potential participants gave consent for their anonymised data to be used at the beginning of the survey. Dairy farmers on the island of Ireland were recruited to participate in an online survey between January and July 2021. Survey inclusion criteria were farmers whose main agricultural sector was dairy cattle and who were at least 18 years old. Participants were purposively sampled, and recruitment strategies included sharing the online survey link with dairy farmers via text, email, social media posts, WhatsApp groups and farmer newsletters. In line with data protection regulations, recruitment was assisted by DAERA (Department of Agriculture, Environment and Rural Affairs), Ulster Farmers Union, farm advisory organisations and dairy manufacturers. Due to the utilisation of numerous organisations to recruit participants, the number of farmers who received recruitment

information is not known and so the response rate of this study cannot be determined. Participants completed the survey voluntarily and were incentivised for their time on completion with a £15/€15 voucher.

4.2.2 Procedure

The survey was administered online using SurveyMonkey. A participant information sheet was provided at the beginning of the survey. Those who chose to participate then gave their consent electronically. Participants were asked which agricultural sector they worked in and their age in order to confirm eligibility before progressing with the survey. Sociodemographic information such as gender, education level, marital status and household income were obtained at the end of the survey. The survey consisted of 39 questions and took approximately 20-25 minutes to complete. A copy of the full questionnaire can be found in appendix 2b. This study was conducted in collaboration with a Safefood Ireland project which explored the knowledge, attitudes, and perceptions of farmers in multiple livestock sectors on the island of Ireland, to AMR and AMU.

4.2.3 Measures

Items included in the questionnaire were based on the COM-B model of behaviour change (Michie, van Stralen & West, 2011) in relation to AMU practices and the development of the scale was informed by Boateng et al. (2018). Potential questionnaire items were generated by conducting an extensive search of relevant literature. Constructs were clearly defined and *n*=8 stakeholders who were deemed experts in the area were consulted to evaluate the relevance, representativeness and technical quality of the items generated. This consultation was conducted by members of the Teagasc team working on the Safefood project previously mentioned. To check the validity of the survey, the survey was pilot tested by conducting face to face cognitive interviews with *n*=10 farmers. Farmers were asked to 'think aloud' as they responded to each item in the questionnaire. This assessed the scale in four areas: comprehension, retrieval, decision process and response process (Ryan et al., 2012). The wording and structure of questions and response options was refined based on this feedback. Table 5 outlines the scales and example questions used for each of the COM-B variables.

All but one of the survey questions used a 5-point Likert scale for participant responses. The one exception to this was a question given to the participants relating to blanket antibiotic use. The following scenario was presented: *"John is a farmer who has recently made changes to how he uses antibiotics. He made a plan to manage his herd's health and prevent disease occurring. He now no longer uses antibiotics with his whole herd to prevent disease breaking out (blanket use) and where possible only gives antibiotics to the animals who show clinical signs of disease".* Farmers were then

asked to indicate whether they have made changes similar to John (i.e., stopping blanket use of antibiotics). *Responses were "yes" or "no".*

This research has been carried out as part of a wider research project, additional questions relating to Covid-19, services availed of by farmers from their vet and farm advisors have not been reported within this thesis but were also asked of participants.

Table 5: Overview of the survey scales used to explore COM-B variables relating to dairy farmers antibiotic use behaviours

Variables and relevant survey items	**Cronbach's alpha**	**Survey question***
Behaviour variables		
Current antibiotic use behaviours[1] 1: I follow the dosage instructions given by the veterinarian when using an antibiotic 2: I follow the instructions given by the veterinarian on how to administer an antibiotic 3: I follow the instructions for storing antibiotics safely (e.g., refrigeration) 4: I store antibiotics in a secure location such as a locked fridge or medicine cabinet 5: I follow the instructions for disposing of antibiotics safely once they are expired or empty 6: I record the antibiotic usage on my farm 7: If the animal looks better, I stop the antibiotic before the end of the prescription 8: I give the full course of antibiotics as written in the prescription 9: I keep a stock of antibiotics on my farm to treat common diseases 10: Giving antibiotics to animals to prevent disease (e.g., blanket use) is part of my animal health management routine 11: If an animal gets sick, I give antibiotics to the whole group to prevent the spread of disease 12: I share antibiotics with other farmers if they are stuck. 13: I get the antibiotics I use on my farm directly from a veterinarian 14: When animals get sick, I use antibiotics before consulting a veterinarian. *Original scale: 1=Never 5=Always (Depending on the specific behaviour, some items were reverse coded for analysis so that a higher score indicated more desirable/ prudent behaviour). Recoded scale: 1=Negative behaviour 5=Positive behaviour*	.673	Q.7
Selective dry cow therapy[2] Farmers were provided with a scenario relating to AMU on farm and asked to indicate whether they have made changes similar to John (i.e. stopping blanket use of antibiotics). *Responses were "yes" or "no".* The scenario was: *"John is a farmer who has recently made changes to how he uses antibiotics. He made a plan to manage his herd's health and prevent disease occurring. He now no longer uses antibiotics with his whole herd to prevent disease breaking out (blanket use) and where possible only gives antibiotics to the animals who show clinical signs of disease".*	n/a	Q.19
Capability variables		
Subjective Knowledge[1] 1: I am aware of/ about how to use antibiotics 2: I feel like I have enough knowledge about antibiotics 3: Compared to the average farmer, I know a lot about how to use antibiotics 4: I believe I use antibiotics responsibly on my farm *Scale: 1=strongly disagree 5=strongly agree*	.706	Q.11
Objective knowledge[1] 1: Antibiotics can kill bacteria 2: Overuse of antibiotics makes them become ineffective to treat animals 3: The active ingredient in antibiotics given to farm animals are the same as those given to humans 4: Overuse of antibiotics makes them become ineffective to treat humans 5: Bacteria resistant to antibiotics in farm animals can be transferred to humans 6: Antibiotics can kill viruses 7: Certain antibiotics are reserved for human use *Scale: 1=correct & very unsure, 2=correct & quite unsure, 3=correct & slightly unsure, 4=correct & quite sure, 5=correct & very sure*	.710	Q.12
AMR and One Health awareness[1]	n/a	Q.13

I am aware of the issue of antibiotic resistance Antibiotic resistance is a problem in my country and worldwide Antibiotic resistance is an issue that could affect me or my family I am aware of the topic of one health I am aware of the links between animal health practices and human health I am aware of the link between antibiotic use on farm for antibiotic resistance in humans *Responses were "yes" or "no".*		Q.14
Opportunity variables		
Peer support[1] How often do you get advice from other farmers on the following? 1: To get advice on herd health management 2: To get advice on reducing antibiotic use 3: To get advice on vaccine programmes 4: To get advice on biosecurity 5: To get advice on treating sick animals 6: To get advice on animal nutrition *Scale: 1= Never 5= Always*	.906	Q.29
Social Pressure[1] 1: I feel under pressure from consumers to reduce antibiotics used on my farm the way I use antibiotics on my farm 2: I feel under pressure from the Department of Agriculture (DAFM/DAERA) to reduce the antibiotics used on my farm 3: I feel under pressure from my veterinarian to reduce AMU the way I use antibiotics on my farm 4: I feel under pressure from my farm advisor to reduce antibiotics usage on my farm *Scale: 1=strongly disagree 5=strongly agree*	.746	Q.25 Q.28 Q.30
Motivation variables		
Perceived Blame[1] 1: I believe antibiotics are used too much in agriculture 2: I believe antibiotics are used too much in human medicine 3: I believe antibiotics are used too much in my sector 4: I believe antibiotics are used too much in other sectors *Scale: 1=strongly disagree 5=strongly agree*	.789	Q.10
Concern[1] How concerned are you about antibiotic resistance for… 1: your animal's health 2: your health 3: your family's health *Scale: 1=Not at all concerned 5=Extremely concerned*	.880	Q.15
Perceived Risk[1] 1: The risks to the average person of antibiotic resistance are… 2: The risks to animals in other sectors of antibiotic resistance are… 3: The risks to my animals of antibiotic resistance are … 4: The risks to my family and me of antibiotic resistance are…. *Scale: 1=Very low 5=Very high*	.877	Q.16
Professional Identity[1] A good farmer… 1: is progressive in using new farming approaches and strategies 2: makes decisions based on evidence and data 3: keeps up to date with latest scientific advice & recommend practice *Scale: 1=strongly disagree 5=strongly agree*	.864	Q.17
Professional Responsibility to make changes to reduce AMR[1] Items n=12. Stakeholders included: Food Consumers. Food Processors/ manufacturers. Restaurants/fast food chains/caterers. Farmers in my sector. Farmers in other sectors. Retailers. Government Departments (including DAFM, DAERA). Medical doctors. Veterinarians. Scientists. Pharmaceutical companies. Public Organisations (e.g. NHS, HSE, WHO) *Scale: 1=Not at all responsible 5=Extremely responsible*	.899	Q.18

Emotions if farmers had to stop blanket use of antibiotics[1] 1: Dissatisfied (= 1) and Satisfied (= 5) 2: Foolish (= 1) and Wise (= 5) 3: Worried (= 1) and Calm (= 5)	.871	Q.20
Self-Efficacy[1] 1: I am confident that I can make changes similar to John on my farm 2: I am confident that I would know what to do 3: I believe I have the ability to make changes similar to John *Scale: 1=strongly disagree 5=strongly agree*	.784	Q.21

[1]Predictor variable for logistic regression
[2]Outcome variable for logistic regression
[*] Relevant survey questions can been seen in supplementary materials

4.2.4 Data analysis

All data was analysed using IBM SPSS Statistics version 25. Descriptive statistics (mean, SD, percentages) were used to explore individual level data.
ANOVA, independent sample t-tests and paired sample t-tests were used to compare differences in responses amongst participants within the data.

ANOVA was used to test differences between groups (age groups [18-39, 40-59, 60+ years], years farming experience [less than 10 years, 11-30 years, 31-50 years, 50+ years] and herd size [less than 50, 50-99, 100+ cattle]) in regard to having stopped blanket use of antimicrobials.

Independent samples t-tests were used to test for significant differences between farmers from Northern Ireland compared with Republic of Ireland and different gender with regards to having stopped blanket use of antimicrobials.

Paired samples t-tests were used to compare the means of questionnaire items and identify significant differences between farmer responses to different questions. Specifically, they were compared with regards to what extent responsible farmers perceived their use of antibiotics on farm to be responsible and their reported actual AMU practices individual practices. That is, to explore whether farmers who *believe* they use antimicrobials responsibly on their farm *actually* practice AMU responsible behaviours (as assessed by self-report).

Pearson's correlation was used to determine whether there was a significant relationship between participants' objective and subjective knowledge of antibiotics and antibiotic resistance and their current responsible AMU practices.

Likert scale items were translated into mean scales based on which element of the COM-B model they related to. Items included in these scales can be seen in table 5 above.

Cronbach's alpha coefficients were determined for each of the scales (also reported in table 3) to measure the internal consistency of each set of survey items (ideal coefficient value used .07). The

means for each set of survey items (scales) were then selected for the regression, variables relating to the COM-B model were used for the regression. ANOVA previously identified no significant difference based on demographic factors relating to stopping blanket use of antimicrobials and therefore they were excluded from the regression model.

Logistic regression was used to determine COM-B predictors of stopping blanket antibiotic use. Several tests were involved to assess the usefulness, convenience, and sufficiency of the fitted model. Hosmer & Lemeshow test determined the goodness of fit, Omnibus test of model coefficients determined the statistical significance of the overall model. By default, a case is classified as the target category if the probability of the target event is greater than or equal to .5 for that case. Otherwise, the case is classified as the non-target event. So, the percentage of correct classification figures represent the specificity and sensitivity when the cut-off value for the predicted probability = .5 by default.

4.3 Findings

4.3.1 Demographic characteristics

A total of 240 participants completed the survey, all were farmers whose main farm work focused on dairy cattle. The demographic characteristics of participants are shown in table 6.

Table 6: Demographic characteristics of farmer survey participants

Characteristic		**N=240**	
		N	**%**
Age group	18-39	72	30
	40-59	127	52.9
	60+	41	17.7
Farm location	Northern Ireland	154	64.2
	Republic of Ireland	86	35.8
Herd size	1-49 cattle	24	10
	50-99 cattle	83	34.6
	100+ cattle	133	55.4
Gender	Male	208	86.7
	Female	27	11.3
	Prefer not to say/unrecorded	5	2.1
Years farming experience	Less than 10	20	8.3
	11-30	117	48.8
	31-50	89	37.1
	More than 50	14	5.8
Highest level of education	One/two-year certificate in agriculture (e.g., green cert)	93	38.8
	Short term agricultural training, less than 60 hours	10	4.2
	Short term agricultural training, more than 60 hours	15	6.3

Third level degree in agriculture	58	24.2
Other (e.g., non-agriculture degree)	11	4.6
None	42	17.5
Prefer not to say/unrecorded	11	4.6

4.3.2 Farmer knowledge & awareness of AMR

Farmers within this study were knowledgeable when it comes to AMU and AMR, both subjectively and objectively. Reported awareness of AMR was also good amongst participants however a lack of awareness of the topic of one health was evident from the participants responses.

Table 7: Overview of participant knowledge & awareness of AMR

Subjective knowledge (Overall mean 3.9542, SD, .49631)	**Mean**	**S.D**
I am aware of/ about how to use antibiotics	4.2458	.58035
I feel like I have enough knowledge about antibiotics	3.6958	.81512
Compared to the average farmer, I know a lot about how to use antibiotics	3.5958	.72549
I believe I use antibiotics responsibly on my farm	4.2792	.57236
Objective knowledge (Mean score 6.3083/7 correct)		**Correct**
Antibiotics can kill bacteria		85%
Overuse of antibiotics makes them become ineffective to treat animals		97.9%
The active ingredient in antibiotics given to farm animals are the same as those given to humans		87.1%
Overuse of antibiotics makes them become ineffective to treat humans		97.1%
Bacteria resistant to antibiotics in farm animals can be transferred to humans		85%
Antibiotics can kill viruses		89.2%
Certain antibiotics are reserved for human use		89.6%
AMR and One Health awareness (Mean awareness 4.783316/6)		Aware
I am aware of the issue of antibiotic resistance		99.6%
Antibiotic resistance is a problem in my country and worldwide		87.5%
Antibiotic resistance is an issue that could affect me or my family		85%
I am aware of the topic of one health		25.8%
I am aware of the links between animal health practices and human health		88.3%
I am aware of the link between antibiotic use on farm for antibiotic resistance in humans		92.1%

4.3.3 Farmer attitudes towards AMR; risk perception, concern & responsibility

Farmers were more concerned about antibiotic resistance for the health of their families (M=3.6542, SD=1.06739) than they were for their own health (M=3.4833, SD=1.10898; $t(239) = -5.674$, $p<.001$, two-tailed). Despite greater concern for their families health, participants believed that the risk of antibiotic resistance to the average person (M=3.0208, SD=.83063) was greater than the risk to themselves and their families (M=2.8250, SD=.92986; $t(239) = 4.215$, $p<.001$, two-tailed). The risk posed by antibiotic resistance to the average farm animal (M=3.1042, SD=.82937) was also

considered greater than the risk posed to the participants own animals (M=2.6083, SD=.89905, $t(239) = 11.221$, p<.001, two-tailed). Despite awareness of the risks posed by antibiotic resistance, farmers seem to exhibit some optimistic bias when it come to their own perceived risk.

When asked about antibiotics being used too much in certain sectors (scale 1 = strongly disagree, 5 = strongly agree), farmers believed that antibiotics were overused significantly more in human medicine (M=3.65, SD=.87) than in agriculture (M=3.35, SD=.98) (means significantly different to p<.001 according to paired samples t-test) and that antibiotics were used much more in other sectors (M=3.55, SD=.84) than their own sector (M=3.20, SD=.99) (means significantly different to p<.001 according to paired samples t-test).

Participants considered pharmaceutical companies (M=4.42, SD=.79) and veterinarians (M=4.34, SD=.75) to be the stakeholders most responsible for taking action to reduce the risk of antibiotic resistance for humans and animals with more responsibility being placed on them than farmers in their own sector (M=4.09, SD=.79). (Scale 1=Not at all responsible 5=Extremely responsible).

4.3.4 Relationship between knowledge and responsible AMU behaviour

Pearson's correlation was used to determine whether there was a significant relationship between participants' objective and subjective knowledge of antibiotics and antibiotic resistance and how responsible their current practices were. Objective knowledge refers to accurate stored information, whereas subjective knowledge refers to self-beliefs about ones own knowledge (Carlson et al., 2009) There was no significant relationship between objective knowledge score and current AMU practices. Subjective knowledge however was significantly correlated with current AMU practices. Participants with higher subjective knowledge scores were more likely to have reported more responsible current behaviours $r(240) = .35$, $p < .001$.

4.3.5 Current AMU behaviours reported by farmers

Farmers were asked to select how often they report particular behaviours related to AMU on farms. Table 8 below shows farmer responses to each behaviour. The mode value for each question is emphasised in **bold**. Mean values included represent the mean of the original responses provided by participants i.e., how often they perform a certain practice. Individual practice means were subsequently recorded to represent how responsible participants AMU behaviours were, as explained in the methods section of this chapter.

Table 8: Current AMU practices reported by dairy farmer survey respondents

	Never	Rarely	Sometimes	Frequently	Always	I don't know/not reported	Mean
I follow the dosage instructions given by the vet when using an antibiotic	0.4%	0.4%	1.3%	9.2%	**88.8%**	-	4.8542

I follow the instructions given by the vet on how to administer an antibiotic	-	-	0.4%	8.3%	**90.8%**	0.4%	4.9079
I follow the instructions for storing antibiotics safely (e.g. refrigeration)	-	0.8%	6.3%	20.8%	**72.1%**	-	4.6417
I store antibiotics in a secure location such as a locked fridge or medicine cabinet	0.8%	5.4%	10%	20.4%	**63.3%**	-	4.4000
I follow the instructions for disposing of antibiotics safely once they are expired or empty	3.8%	5%	17.1%	21.7%	**49.2%**	3.3%	4.1121
I record the antibiotic usage on my farm	-	1.7%	4.2%	26.3%	**67.9%**	-	4.6042
If the animal looks better, I stop the antibiotic before the end of the prescription	**47.9%**	20.4%	22.1%	8.8%	0.8%	-	1.9417
I give the full course of antibiotics as written in the prescription	-	0.8%	7.1%	31.7%	**60.4%**	-	4.5167
I keep a stock of antibiotics on my farm to treat common diseases	4.6%	16.3%	23.3%	24.2%	**31.3%**	-	3.6292
At certain times I give antibiotics to animals to prevent disease (i.e. blanket use)	**46.3%**	23.8%	16.7%	7.1%	5.4%	0.8%	2.0417
If an animal gets sick, I give antibiotics to the whole group to prevent the spread of disease	**53.8%**	30.4%	13.8%	1.3%	0.8%	-	1.6500
I share antibiotics with other farmers if they are stuck.	**71.3%**	19.2%	8.3%	0.8%	-	0.4%	1.4083
I get the antibiotics I use on my farm directly from a vet	0.8%	0.8%	1.7%	5%	**91.3%**	0.4%	4.8667
When animals get sick, I use antibiotics before consulting a vet.	**10.8%**	16.7%	50%	20.8%	1.7%	-	2.8583

4.3.6 Farmer perceptions of current AMU practices

Paired samples t-tests were used to determine whether or not there were any significant differences between participants' responses to individual questionnaire items. When asked about responsible AMU on farms, overall participants felt that they used antibiotics responsibly (Mean= 4.28, SD= .57, scale 1 = strongly disagree, 5 = strongly agree). However, when asked about individual practices (which collectively determine "responsible AMU") generally it was reported that they use antibiotics before consulting a veterinarian (Mean= 3.14, SD= .93, scale 1 = very irresponsible practice, 5 = very responsible practice), kept a stock of antibiotics on farm to treat common disease (Mean= 2.38, SD= 1.21, scale 1 = very irresponsible practice, 5 = very responsible practice) and that giving antibiotics to prevent disease was part of their animal health management routine (Mean= 3.99, SD= 1.19, scale 1 = very irresponsible practice, 5 = very responsible practice), all of which are considered irresponsible/imprudent AMU behaviours. The difference between the mean for responsible antibiotic use and the means for the subsequent three behaviour questions were significant compared to the paired samples t-test $p<.001$.

Additionally, farmers generally strongly agreed that they "always" followed veterinarian instructions on how to administer antibiotics (Mean= 4.91, SD= .30, scale 1 = very irresponsible practice, 5 = very responsible practice), however when asked about individual practices related to following

veterinarian instructions reply not all farmers always give the full course of antibiotics as written on the prescription (Mean= 4.52, SD= .67, scale 1 = very irresponsible practice, 5 = very responsible practice) and some also admitted to stopping AMU if the animal looks better before giving the whole prescription (Mean= 4.06, SD= 1.06, scale 1 = very irresponsible practice, 5 = very responsible practice). The differences between the mean for always following veterinarian instructions (4.91) and two subsequent means relating to veterinarian instructions (4.52 and 4.06) were significant according to the paired samples t-test $p<.001$.

4.3.7 Farmers perceptions of stopping blanket AMU

Participants were asked in relation to the John scenario whether or not they had made similar changes i.e. whether they had stopped blanket AMU, 189 farmers reported that they had made changes similar to John (78.8%) while 51 reported that they had not made similar changes (21.3%).

Participant farmers were also asked to report how they would feel if they made such changes and stopped blanket AMU and also to determine their confidence and belief in their ability to make such changes.

Table 9 below illustrates the responses provided by participants on how they would feel if they were to make changes similar to John and stop blanket AMU amongst their dairy cattle. The results show that farmers surveyed would feel slightly less calm than they would feel satisfied or wise if they were to stop blanket AMU.

Table 9: Dairy farmers reported emotions related to stopping blanket AMU

Emotion scale	Mean	S.D
1= Dissatisfied to 5= Satisfied	4.05	1.042
1= Foolish to 5= Wise	4.15	.901
1= Worried to 5= Calm	3.61	1.148

Table 10 below presents the mean findings in response to statements provided to farmers relating to their confidence and ability to make changes similar to John i.e. to stop blanket AMU. Farmers surveyed had a slightly higher mean belief that they had the ability to make similar changes than they were confident that they could and would know how to make such changes.

Table 10: Dairy farmers reported confidence and ability to stop blanket AMU

Statement	Mean	S.D
I am confident I can make changes similar to John	3.9167	.88770
I am confident that I would know what to do	3.8333	. 83173
I believe I have the ability to make similar changes	4.0125	. 74024

**5 point Likert scale used for statements 1=strongly disagree 5=strongly agree*

4.3.8 Predictors of farmers stopping blanket AMU

Binary logistic regression assessed the impact of a number of factors on the likelihood that farmers would report that they had made changes to their blanket use of antibiotics based on the scenario provided about John.

The model contained 12 predictor variables (table 11). Omnibus test of model coefficients determined that the model is statistically significant (p <.001), indicating that the model was able to distinguish between respondents who reported and did not report making changes to their blanket AMU. The model as a whole explained between 22.0% (Cox and Snell R square .220) and 34.1% (Nagelkerke R squared .341) of the variance in stopping blanket AMU (this is how far observed values differ from the average predicted values) and correctly classified 85% of cases (the model has a very good classificatory power at 0.5 cut-off value). Hosmer & Lemeshow goodness of fit test confirmed that the model is a good fit to the data (Chi-square 7.159, df 8, p.520) (Table 12).

Table 11: Regression model predicting likelihood of farmers making changes similar to John i.e. stopping blanket AMU

							95.0% C.I. for Odds Ratio	
	B	S.E	Wald	df	P	Adjusted Odds Ratio	Lower	Upper
Mean Behaviour	-.255	.528	.232	1	.630	.775	.275	2.184
Mean Perceived Blame	-.355	.291	1.490	1	.222	.701	.396	1.240
Mean Subjective Knowledge	.815	.448	3.304	1	.069	2.259	.938	5.441
Mean Concern	-.124	.246	.253	1	.615	.883	.545	1.431
Mean Perceived Risk	-.046	.294	.025	1	.875	.955	.537	1.698
Mean Emotions	1.037	.206	25.418	1	**<.001****	2.822	1.885	4.224
Mean Pressure	.513	.244	4.407	1	**.036***	1.670	1.035	2.697
Mean Peer Support	.148	.263	.316	1	.574	1.160	.692	1.943
Score Objective Knowledge	-.528	.230	5.274	1	**.022***	.590	.376	.926
AMR Awareness	.903	.301	9.001	1	**.003****	2.467	1.368	4.449
OH Awareness	.286	.250	1.309	1	.253	1.332	.815	2.175
Professional Identity	.556	.280	3.946	1	**.047***	1.744	1.007	3.019
Constant	-6.569	2.822	5.420	1	.020	.001		

** = significant to < 0.05 ** = significant to < 0.01*

As shown in table 11, five predictor variables made a statistically significant contribution to the model (emotions related to stopped blanket AMU, professional identity (perceptions of what makes a good farmer), pressure to reduce AMU, objective knowledge and AMR awareness). The strongest predictors of stopping blanket dry cow therapy were AMR awareness and associating more positive emotions with reducing AMU, recording odds ratios of 2.467 (95% CI [1.368, 4.449]) and 2.822 (95% CI [1.885, 4.224]) respectively. This indicated that the more awareness of AMR and the more positive emotions associated with stopping blanket use of antibiotics were, the more likely they were to have reported stopping blanket use of antimicrobials. Feeling more pressure to reduce AMU as well as scoring lower overall for objective knowledge were also predictors of respondents having stopped blanket use of antimicrobials.

Table 12: Logistic regression outcomes for model significance, variance and goodness of fit.

Omnibus Tests of Model Coefficients				
		Chi-square	Df	Sig.
Step 1	Step	59.574	12	**<.001**
	Block	59.574	12	**<.001**
	Model	59.574	12	**<.001**
Model Summary				
Step	-2 Log likelihood		Cox & Snell R Square	Nagelkerke R Square
1	188.706		.220	.341
Hosmer and Lemeshow Test				
Step	Chi-square		Df	Sig.
1	7.159		8	.520

Pearson's correlation tests were used to explore relationships between the positive predictors of stopping blanket use of antibiotics. Mean objective knowledge positively correlated with mean AMR awareness ($r(238) = .36$, $p=<.001$). i.e. having greater objective knowledge correlated with having greater AMR awareness.

4.3.9 Potential behaviour change interventions to promote farmers stopping blanket AMU.

As outlined in section 2.4.2, the BCW can be used to identify intervention functions and policy categories which are more likely to result in successful behaviour change interventions. The predictors of farmers stopping blanket AMU were linked to intervention functions and policy categories in this manner and table 13 below provides an overview of this, with some potential behaviour change interventions proposed which will be discussed further at the end of the following section.

Table 13: Mapping the COM-B components which predict farmer behaviour relating to blanket AMU to potential intervention functions and policy categories.

Predictor	**COM-B component**	**TDF**	**Intervention functions**	**Policy categories**	**Potential behaviour change intervention**
Knowledge and awareness of AMU and AMR	Capability – psychological	Knowledge	Education	Communication/ marketing Guidelines Regulation Legislation Service provision	Education to increase farmer knowledge and awareness of AMR
Farmer skills to use antimicrobials responsibly	Capability – physical	Physical skills	Training	Guidelines Fiscal measures Regulation Legislation	Providing training to impart the skills needed to reduce AMU while maintaining herd health and farm productivity
Pressure to reduce antimicrobial use on farm	Opportunity - social	Social influence	Restriction Environmental restructuring Modelling Enablement	Communication/ marketing Guidelines Fiscal measures Regulation Legislation Environmental/ social planning Service provision	Placing restrictions on farmers to encourage prudent AMU or modelling to provide an example for farmers to aspire
Emotions associated with stopping blanket use of antimicrobials	Motivation – automatic	Emotions	Persuasion Incentivisation Coercion Modelling Enablement	Communication/ marketing Guidelines Fiscal measures Regulation Legislation	Persuasion involving communication to induce positive feelings in relation to reducing AMU and interventions

				Service provision	to enable farmers to overcome the barriers they face when trying to reduce AMU
Farmers professional identity and being a 'good farmer'	Motivation – reflective	Professional/ social role & identity	Education Persuasion Modelling	Communication/ marketing Guidelines Regulation Legislation Service provision	Persuasion techniques such as positive reinforcement and feedback to encourage more responsible AMU and build professional identity of farmers

4.4 Discussion

4.4.1 Farmer attitudes towards AMR – Risk perceptions & farmer role in AMR stewardship

Optimism bias is a cognitive bias causing an individual to underestimate the possibility of negative events whereby they believe themselves to be less likely to experience a negative event (Sharot, 2011). Findings within this study imply that despite having a relatively good knowledge of AMR and the risk it can pose, farmers risk perceptions are skewed based on who their concern is aimed at i.e., farmers feel that themselves and their animals are less at risk than other humans and animals. This display of optimism bias has been found in previous research of farmers relating to AMU. Indonesian poultry farmers previously reported optimism bias, believing that AMR would not be an issue on their farms (Coyne et al., 2020). Excessive optimism can be hazardous as underestimating risk may reduce precautionary behaviours (Sharot, 2011). This suggests that education of farmers to raise awareness and understanding of the risks posed from AMR is needed in order to overcome these misconceptions that farmers and their animals are less susceptible to the risks than others.

External attribution of responsibility to others is a major barrier to behavioural change and must be understood, accounted for and managed in policy development (Ruegg et al., 2017). Farmers within this study believed that antibiotics are used too much in human medicine compared with agriculture as well as too much in other farming sectors compared with their own. These findings suggest that not all farmers recognise the role they play in the development and spread of AMR. Placing the blame for increased AMR and imprudent AMU on other parties has been observed previously by stakeholders in both human and veterinary medicine (Labi et al., 2018; Golding et al., 2019; Hardefeldt et al., 2018; Nicholson et al., 2018). Previous literature recommended that shared responsibility between farmers and veterinarians may help behaviour change as there is evidence

that farmers intentions to change is reinforced by mutual support from their major referents which includes veterinarians and other advisors (Ellis-Iversen et al., 2010). In order to overcome this other-blaming, future research should focus on enabling farmers to work alongside other stakeholders confidently and effectively to achieve the common goal of reducing AMU on dairy farms (Farrell et al., 2021). This suggests that increasing farmer awareness of the role they play in AMR and encouraging collaboration with veterinarians to enhance a shared responsibility for AMR stewardship is needed.

Previous literature advised that enabling behavioural change requires farmers and veterinarians to perceive their own personal roles and actions as efficacious and important in relation to AMR (Fishbein & Cappella, 2006). Additionally, when asked about who was responsible for taking action to reduce the risk of AMR for humans and animals, despite placing some responsibility on themselves, pharmaceutical companies and veterinarians were considered significantly more responsible than farmers in their own sector. Previously responsibility has been found as the greatest contributor to farmers' willingness to support environmental protective policy (Montada & Kals, 2000). Therefore, in order to encourage farmers to make changes to their AMU behaviours it is important that they take responsibility for their role in helping to prevent AMR. Recently being aware of the consequences of their actions and taking responsibility for their behaviour was reported as having a significant effect on farmer behaviours relating to water conservation (Savari et al., 2021). This suggests that increasing farmers' awareness of the consequences of not taking action against AMR is therefore necessary to enable them to take responsibility for their behaviour. Additionally, as previously recommended, improving farmers understanding of the risk posed to themselves and others as a result of AMR and their AMU practices may aid with improving farmers perceptions of the role they can play in helping to tackle the issue of AMR.

4.4.2 Farmer perceptions of current behaviours

Almost all farmers believed that they used antibiotics responsibly. However, when asked about specific behaviours many admitted to behaviours which are considered irresponsible. These findings suggest that farmers unknowingly perceive their individual AMU practices to be more responsible than they actually are. Similarly, it was reported by previous literature that 65% of Ugandan poultry farmers surveyed believed they used antimicrobials in accordance with veterinary guidelines, however only 16% actually complied with guidelines (Kigozi & Higenyi, 2017). Likewise, another study of farmers and veterinarians reported that they demonstrated a good understanding of AMR stewardship, but their treatment decisions are not always aligned to stewardship principles (Golding et al., 2019). This suggests that in order to overcome this mismatch in farmers perceived responsible use and their reported AMU practices, education, and training on what constitutes responsible AMU

practices are necessary. Training is needed to enable farmers with the skills to effectively implement responsible AMU practices on farm. Such education could improve farmers awareness that in some instances their behaviours do need to change and that there is room for improvements to their current practices. Additionally, monitoring farmers use, and farming practices related to antimicrobials over time with feedback provided on their progress could help motivate farmers to change their practices and maintain new behaviours.

This non-alignment of perceived behaviour and actual behaviour could also partially be a result of social desirability which is the tendency of individuals to deny socially undesirable actions and behaviours and to admit to socially desirable ones (Zerbe & Paulhus, 1987). It could also be that farmers' AMU behaviours are habitual and so they are not always aware of whether what they are doing is responsible. Habit is hypothesised to have two interrelated effects on behaviour: firstly, where associated with commonly encountered cues, habit prompts frequent performance; and secondly, in the presence of these cues, habits may dominate over intentions in regulating action (Hall & Fong, 2007; Triandis, 1997). As experience of a behaviour is acquired, the influence of habit increases, and that of intention declines (Triandis, 1997), having used antibiotics previously to treat their animals, farmers may therefore see the value in their habitual actions and consider their behaviour responsible as it protects their animals at that moment. Therefore, despite being aware of the risks associated with AMU, when faced with the decision to treat animals using antibiotics, habit may be the reason for irresponsible practices. Previous research has also found habit and previous experience to play a role in veterinarians antimicrobial use practices (Coyne et al., 2016; Doidge et al., 2019). Again, this suggests that ongoing education programs are needed to raise farmer awareness of responsible practices and encourage uptake of responsible AMU practices.

4.4.3 Predictors of farmers stopping blanket antibiotic use

Some variables relating to capability (AMR awareness and objective knowledge), opportunity (pressure to reduce AMU) and motivation (emotions associated with stopping blanket AMU and perceptions of what shapes a "good farmer") predicted whether or not dairy farmers had made changes to stop blanket use of antibiotics. Farmers who were more aware of AMR, felt some pressure to reduce AMU and associated positive emotions with stopping blanket AMU, were more likely to have stopped blanket use of antimicrobials. Additionally, contrary to expectations, having greater objective knowledge relating to AMR was associated with decreased odds of stopping blanket antibiotic use. As items relating to capability, opportunity and motivation all significantly predicted the outcome behaviour of stopping blanket use of antimicrobials, the use of the COM-B model in relation to dairy farmers AMU behaviours can be considered informative.

Capability: Increasing knowledge and awareness of AMU and AMR can positively influence attitudes towards AMR stewardship strategies and increase farmers' interest in their implementation (McKernan et al., 2021). In this study having lower objective knowledge of AMU and AMR and having greater awareness of AMR were significant predictors of farmers stopping blanket use of antimicrobials. When it comes to behaviour change, knowledge is important but not enough as many other factors can prevent the desired behaviour of reduced antibiotic use (Chambers et al., 2020; Servia-Dopazo et al., 2021). Education to increase general knowledge in regard to health behaviour change is rarely needed, it is education to increase awareness of the issues and training on how to change behaviours which is necessary (Arlinghaus & Johnston, 2017). This is confirmed by the regression in this study finding that while greater awareness of AMR predicts whether or not an individual is likely to have made changes away from blanket use of antimicrobials, having greater objective knowledge of AMR was associated with a reduced likelihood of having stopped blanket use of antimicrobials.

Having greater awareness of AMR was associated with increased likelihood of stopping blanket use of antimicrobials in this study. This is supported by previous research in which dairy farmers who were aware of the benefits associated with reduced AMU had a more positive outlook on SDCT (Huey et al., 2021). This suggests that behaviour change interventions should include a component of increasing AMR awareness amongst dairy farmers and the impact their behaviour can have to help encourage change to dairy AMU.

Based on the intervention function of the BCW, to improve knowledge and awareness, behaviour change interventions should focus on education and training (Michie, Atkins & West, 2014). Education could increase knowledge and understanding of AMR to increase farmers' awareness of their role in tackling AMR. Providing training to impart the skills needed to reduce AMU while maintaining herd health and farm productivity could be incorporated into behaviour change interventions to improve capability to reduce AMU.

Opportunity: Social pressure has been reported previously as a significant determinant of farmer behaviour in relation to grassland management (Martínez-García et al., 2012), animal welfare behaviours (Kauppine et al., 2013), and pro-environmental management (Mills et al., 2017). Recently, regulatory pressure was cited as the most common reason for farmers moving away from BDCT and starting SDCT (Huey et al., 2021). Feeling some degree of pressure to reduce AMU from stakeholders such as veterinarians and government agricultural departments was a significant predictor of farmers having stopped blanket use of antimicrobials in this current study. An agricultural review into farmer decision making found farmers may be apprehensive or fearful of

trying new behaviours and suggested creating societal pressure, amongst other techniques, as a way of overcoming such fears (Rose et al., 2018). To encourage farmer to move away from blanket antibiotic use and towards more responsible AMU overall on dairy farms, societal pressure to conform should be considered when designing behaviour change interventions.

Based on the intervention function of the BCW, to increase societal pressure, behaviour change interventions should focus on restrictions and modelling (Michie, Atkins & West, 2014). Placing restrictions on farmers to encourage prudent AMU or modelling to provide an example for farmers to aspire to, e.g., a farmer promoting responsible AMU and SDCT to their farming peers, could increase societal pressure felt by dairy farmers and lead to reduced AMU. Within this current study social pressure came from various groups (i.e., veterinarians, farm advisors, consumer and government bodies), therefore benefits may be gained in targeting social pressure interventions at these groups as well which could feed back to farmers and help change their behaviour. Given the importance of factors such as self-efficacy and emotion, it is key that restrictive interventions if imposed, take place in an environment where bottom-up, enabling interventions are also present. Bottom-up approaches are initiated and driven by individuals whom a particular behaviour is aimed at, as opposed to top-down interventions which are initiated and driven by senior management or authority figures for example (Björk et al., 2021).

Motivation: Emotional responses associated with stopping blanket use of antimicrobials and moving towards SDCT has been reflected in previous literature as fears for animal welfare, farm productivity and financial uncertainty, have been reported by dairy farmers as barriers to reducing AMU (Farrell et al., 2021; Orpin, 2017; Poizat et al., 2017). In the current study those who had stopped blanket use of antimicrobials, associated more positive emotions with making such changes i.e., feeling more calm, wise and satisfied. Fear associated with antibiotic dry cow therapy and mastitis has been commonly reported by dairy farmers and is a significant challenge when trying to promote uptake of SDCT (Scherpenzeel et al., 2016). Although fear was not directly measured within this study it makes sense that improving farmer's emotional response to stopping blanket use of antimicrobials should overcome any fears farmers have of mastitis when reducing AMU. Associating positive emotions to reducing AMU positively correlated to greater self-efficacy. Improvements to farmers' self-efficacy relating to reducing AMU on farms, in turn could improve the emotions farmers associate with such changes and therefore help enact behaviour change.

Based on the intervention function of the BCW, for farmers to associate positive emotions relating to reducing AMU, behaviour change interventions should focus on persuasion and enablement (Michie, Atkins & West, 2014). Persuasion involving communication to induce positive feelings in

relation to reducing AMU and interventions to enable farmers to overcome the barriers they face when trying to reduce AMU (e.g., fear and other negative emotions) could strengthen farmers motivation towards SDCT uptake.

Farmer perceptions of what being a "good farmer" consists of also predicted whether or not they had made changes away from blanket use of antimicrobials. Those who believed that a good farmer is progressive in using new farming approaches and strategies, makes decisions based on evidence and data and keeps up to date with latest scientific advice & recommend practice, were more likely to have moved away from blanket use of antimicrobials. All farmers have their own idea of what it means to be a good farmer and so previous literature explored how a performance based environmental management process could influence farmers social identity and shift overall good farmer identity toward a stronger conservationist standard (McGuire, Morton & Cast, 2013). Continuous feedback in performance based environmental management was found to be able to help farmer activate their conservationist farmer identities to establish new norms for practicing more sustainable agriculture (McGuire, Morton & Cast, 2013). Additionally, social comparison theory which suggests that people value their own personal and social worth by assessing how they compare to others (Festinger, 1954), could be utilised to motivate behaviour change amongst farmers in relation to AMU. This theory proposes that people compare and evaluate their actions, accomplishments, and opinions in contrast to those of other people (Festinger, 1954). Farmer peer support groups may evoke social comparison between farmers and combined with previously recommended training on what constitutes responsible AMU practices, could motivate farmers to change their practices and maintain behaviour change.

Based on the BCW and previous literature, to promote the good farmer identity, behaviour change interventions should focus on education and persuasion (Michie, Atkins & West, 2014). Persuasion techniques such as positive reinforcement and feedback which would include monitoring farmers AMU practices and providing encouragement to use antimicrobials more responsibly, should build farmers confidence in their abilities and also importantly, help establish responsible antimicrobial practice as a new norm for being a good farmer.

Based on these findings it is recommended that future interventions should focus on; increasing farmers awareness of AMR rather than simply aiming to improve their knowledge, improving farmers confidence in their ability to make changes away from blanket use of antimicrobials in order to enable them to associate positive emotions with making such changes, improve their feelings of professional identity as a good farmer, and consider increasing societal pressure felt by farmers to stop blanket use of antimicrobials and make more responsible AMU decisions. By incorporating

these elements into future interventions based on the COM-B model, farmers capability, opportunity and motivation to stop blanket use of antimicrobials could be increased and in turn result in more responsible practices related to AMU on farm.

Relationship between knowledge and current responsible AMU behaviour

There was no significant correlation between overall objective knowledge and reporting more responsible current AMU practices despite objective knowledge being a significant predictor of whether or not participants had stopped blanket use of antimicrobials. This is interesting as a recent systematic review found that elevating farmer knowledge through education influenced AMU and encouraged appropriate practices on farms (McKernan et al., 2021). This strengthens the argument that when it comes to reducing AMU, increasing knowledge is not sufficient to enact behaviour change and a multifaceted approach is necessary when it comes to behaviour change interventions.

4.5 Strengths and limitations

To the best of the authors' knowledge this is the first time the COM-B model has been applied to dairy farmers' behaviour relating to AMU using a quantitative survey method. Despite the potential limitations (7.5.2) these findings highlight the usefulness of the COM-B model and its applicability to this area of research. This research has determined that the COM-B model is useful for the identification of potential predictors of dairy farmers' behaviour and can be used to develop targeted behaviour change interventions. It should be noted that despite these variables being identified as statistically significant predictor variables to stopping blanket AMU within this regression model, due to the observational nature of this work, care should be taken with these findings as regressions are only able to determine associations between variables and not the cause and effect. In order to determine causal inferences a randomised control trial would be necessary.

AMR is currently a very topical global health issue and this survey evaluated self-reported behaviours and attitudes; therefore, findings are subject to aspects of social desirability as it relied on participants to be honest and recall their behaviours accurately. Despite the fact that the survey questions and scale used for data analysis were generated based on an extensive literature review, the scale was not subjected to full psychometric testing which is common in AMR research (Alumran, Hou & Hurst, 2012). In the COM-B model, self-efficacy is an element of motivation and thus a predictor/influencer of behaviour. Therefore, in this study self-efficacy was viewed as an influencer of stopping blanket use of antibiotics. However, it should be acknowledged that changing one's behaviour can also increases an individual's confidence in their ability to carry out a behaviour, increasing their self-efficacy. Additionally, the current studies recruited dairy farmers from the Island of Ireland and so findings may not be fully generalizable to different farming sectors and countries.

This study used the mean values of Likert scale data to interpret results. Some controversy exists around how to best analyse Likert scale data and how useful the mean value truly is (Allen & Seaman, 2007). In order to create scales for the regression analysis, mean values were the most appropriate. In other instances, such as reporting farmers current knowledge and practices for example, the mean value was used. The researcher checked against the original survey data that the mean value reported was representative of the distribution of responses and the mode, which is commonly argued as the best way to report Likert scale data, therefore the data is reliable despite the mean values being reported.

4.6 Recommendations

This research has determined predictors of dairy farmers stopping blanket use of antimicrobials which should be focused on for the creation of future behaviour change interventions aimed at reducing irresponsible AMU on dairy farms. Behaviour change interventions can be determined from these findings using the behaviour change functions determined by the Behaviour Change Wheel (Michie, Atkins & West, 2014). Potential interventions should be subjected to evaluation using the APEASE behaviour change intervention criteria in order to determine their Affordability, Practicality, Effectiveness and cost-effectiveness, Acceptability, Side-effects/safety, and Equity (Michie, Atkins & West, 2014).

Additionally, one surprising finding of the regression was that having a greater objective knowledge of AMU and AMR was associated with a reduced likelihood of stopping blanket use of antimicrobials, when literature suggests the opposite. This may be an important finding for intervention designers as perhaps the drivers of specific AMU behaviours need to be better understood and encouraged rather than just responsible AMU in general.

4.7 Conclusion

Dairy farmers' behaviour in relation to stopping blanket use of antibiotics can be predicted using the COM-B model. In this study, variables relating to capability (lower objective knowledge and greater AMR awareness), opportunity (feeling pressure to reduce AMU) and motivation (greater self-efficacy and associating positive emotions with reducing AMU) are all significant predictors of whether or not dairy farmers have made changes to stop blanket use of antimicrobials. Despite commonly being linked to behaviour change, increasing knowledge of AMR alone is not enough and a multifaceted approach, encompassing each of the predictors highlighted in this study should be taken to encourage farmer behaviour change in relation to stopping blanket use of antimicrobials and reducing overall AMU. Farmers' perceptions of their own behaviours may often be skewed due to habit and many AMU behaviours being common practice for them, therefore awareness raising of

specific behaviours and what constitutes “responsible” AMU behaviour should be targeted at dairy farmers rather than general knowledge transfer. Additionally, findings suggest that interventions also need to consider societal pressure to reduce AMU and improving farmers’ self-efficacy and emotions associated with stopping blanket antibiotic use to improve their chances of successfully changing farmer behaviour away from blanket use of antimicrobials.

4.8 Chapter 4 summary

This chapter provided an overview of the quantitative survey conducted with dairy farmers to determine their knowledge and awareness of AMR, their perceptions related to AMR risks and responsibility for tackling the issue as well as their current AMU practices and what factors predict stopping blanket use of antimicrobials.

5. Chapter 5: Exploring veterinarians' behaviour relating to antimicrobial use on dairy farms (*study 2*)

Study 2: Abstract

Employing a theoretical model of human behaviour (the COM-B model), the current study explores the factors influencing veterinarians' engagement with antimicrobial use stewardship on dairy farms. One-to-one semi structured interviews were carried out by telephone with 12 veterinarians whose daily work focused on dairy cattle. A thematic analysis approach was undertaken, and the identified themes and sub-themes were then mapped to the COM-B model. This study identified challenges faced by veterinarians when trying to prescribe responsibly which included lack of training to encourage farmer behaviour change, issues with laboratory testing, pressures from farmers to prescribe antimicrobials, concern for animal welfare and farmers going elsewhere for prescriptions. Having a good knowledge of AMR, peers as an advice source, potential financial benefits for farmers as a result of reduced antimicrobial costs and accepting a shared responsibility for AMR, facilitate veterinarians in their role as antimicrobial stewards. The barriers and facilitators identified as influencing veterinarians' *capability*, *opportunity,* and *motivation* to responsibly prescribe antimicrobials formed the basis for a number of practical recommendations which should be considered by advisory and policy making teams. Recommendations include; continuous training for veterinarians on AMR and alternatives to overcome the barriers faced when trying to promote reduced AMU, veterinarian peer support groups to improve confidence in their knowledge and decision making to minimize the effect of client pressures/expectations, setting up collaborative farmer and veterinarian working groups to promote a transparent working relationship and the development of affordable and efficient diagnostic and susceptibility testing.

5.1 Introduction

Given the important role that is played by both farmers and veterinarians in relation to AMU on dairy farmers, this chapters adds to the overall aim of the thesis by utilizing an online survey and qualitative telephone interviews with dairy veterinarians based on the systematic review findings (chapter 3) and the COM-B model.

This chapter aimed to extend the current literature by utilising the COM-B model in relation to veterinary antimicrobial prescribing practices on dairy farmers for the first time (COM-B model explained fully in section 2.3.2). The online survey and interview schedules designed with the COM-B model in mind, were used to explore and describe decision-making processes for antimicrobial

prescribing by dairy veterinarians to further understand the components which are most likely to influence responsible antimicrobial prescribing amongst dairy veterinarians.

The findings of this chapter will also help inform policy development and assist with the implementation of evidence-based behaviour change interventions to help promote more responsible antimicrobial prescribing to dairy cattle following evaluation with dairy stakeholders (chapter 6).

5.2 Method

As with the previous chapter, this study was conducted in collaboration with the Safefood project in which similar research was being conducted with veterinarians across various livestock sectors (including dairy cattle, beef cattle, sheep and pig farmers). Members of the research team at Teagasc Mellows campus assisted with survey and interview design and participant recruitment. To achieve the aims of this thesis, the PhD student amended the survey and interview questions where necessary and included only the data collected from veterinarians whose main farm animal work involved dairy cattle for data analysis.

5.2.1 Ethics:

Ethical approval was granted by the Queen's University Belfast School of Biological Sciences Research Ethics Committee (MHL 20_123). The study was conducted according to the guidelines laid out in the Declaration of Helsinki (World Medical Association, 2013). Participants gave their consent verbally at the beginning of the online survey and telephone interview recordings for their anonymised data to be used for this study.

5.2.2 Participant recruitment and procedure:

The current study employed a mixed methods research design. A recruitment email was sent to veterinarians on behalf of the research team by Vet NI and Veterinary Health Ireland. Due to the utilisation of external organisations to recruit participants, the number of veterinarians who received recruitment information is not known and so the response rate of this study cannot be determined.

5.2.2.1 Vet online survey

Participants were invited to complete an online survey using SurveyMonkey which identified the main focus of their farming work. Only those veterinarians whose farm work focused mainly on dairy cattle were eligible for this study. The online survey consisted of 24 questions and took approximately 20 minutes to complete. The survey measures explored veterinarians' objective knowledge of antibiotics and AMR, perceived ability and procedural knowledge, concern for AMR, intentions to use antibiotics responsibly, perception of strategies to help promote more responsible antibiotic use on dairy farms and their opinion on a responsible veterinary antibiotic prescribing scenario provided.

The questions were derived from the literature review outlined in chapter three of this thesis. The online survey was piloted by researchers within the University, members of the Teagasc team, and by a veterinary health expert to ensure accuracy and readability.

Table 14: Overview of veterinarian survey questions including possible responses and Cronbach's alpha coefficients for survey scales.

Objective knowledge of antibiotics and AMR (True/False)	**Cronbach's alpha**
Antibiotics are used to cure infections caused by viruses	**n/a**
Bacteria can become resistant to antibiotics when antibiotics are frequently used	
Overuse of antibiotics can lead to antimicrobial resistance	
Misuse of antibiotics can lead to antimicrobial resistance	
Certain antibiotics are reserved for human use	
Perceived ability and procedural knowledge (1=unskilled 7=very skilled)	**.706**
I am able to identify the correct antibiotic for infection.	
I am able to calculate the correct dose of antibiotics for animals	
I am able to calculate and administer the correct duration the antibiotics are used for	
I am able to record relevant antibiotic usage information for each farm within my practice	
I am able to monitor and record antibiotic use within my practice	
I am able to comply to antibiotic protocols when treating animals	
I am able to educate farmers on the use of alternative therapies to treat common diseases on their farm (e.g. vaccines, anti-inflammatories)	
Concern for AMR (1=not at all concerned 7=extremely concerned)	**.729**
How concerned are you about antimicrobial resistance for humans	
How concerned are you about antimicrobial resistance for animals	
Intentions to use antibiotics responsibly (1=strongly disagree 7= strongly agree)	**.745**
I intend to reduce antibiotic use in my practice	
I intend to use antibiotics responsibly in my practice	
I intend to adhere to antibiotic selection protocols and recommendations before prescribing antibiotics (e.g. susceptibility and diagnostic testing)	
I intend to encourage the implementation of alternative methods to using antibiotics e.g. use of vaccines and herd health planning	
Strategies to help promote more responsible antibiotic use on dairy farms (1=not at all helpful 7=very helpful)	**.789**
Provision of tailored herd health plans and routine visits for clients	
Provide financial incentives or grants to support the use of alternatives to antibiotics such as herd health planning, vaccines etc.	
Improve diagnostic and susceptibility testing procedures	
Mandatory antibiotic use recording for farms	
Put in place new policies and regulations to restrict antibiotic use	
Provide educational training programs for all farmers on antibiotics and preventing infectious disease.	
Provide training and support to improve communication skills of vets	
Assign one contracted vet to a farm	
Mandatory antibiotic prescribing recording for veterinary practices	
Implement legal action should policies and legislation not be adhered to	
Publish antibiotic usage data on each farm 3 times a year	
Compulsory CPD for veterinarians on antibiotic use.	
Uncoupling veterinary prescribing from the sale of antibiotics	
Responsible veterinary antimicrobial prescribing scenario	**n/a**
Participants provided with the following scenario: *"Frank is a vet and his client is a dairy farmer getting ready to dry off his herd. Together with his client, they discuss the latest milk recordings*	

for the herd. Only 7% of cows have high cell counts. Frank decides to prescribe the high cell count cows with dry cow antibiotic tubes and treat the remaining herd with a non-antibiotic teat sealant". Keeping this scenario in mind, veterinarians then indicated how often they made similar decisions to Frank in their practice where 1=never and 7=always.	

At the end of the survey veterinarians were asked to provide their email address if they were willing to also participate in a telephone interview. Eligible veterinarians were then invited to take part in one-to-one semi-structured interviews via telephone lasting approximately 30 minutes. A date and time for the telephone interview was provided to those who agreed to participate. Interviews were carried out by the thesis author and a Research Fellow from Queen's University Belfast with interview experience.

5.2.2.2 Vet telephone interviews

A semi-structured interview guide (Table 15) was used to explore veterinarians (1) knowledge and awareness of AMR (2) motivation and professional role in tackling AMR (3) perceived barriers and facilitators of reducing AMU on dairy farms and (4) perceptions of dairy farmers relating to AMR. The questions were derived from the literature review outlined in chapter three of this thesis. The online survey was piloted by researchers within the University, members of the Teagasc team, and by a veterinary health expert to ensure accuracy and readability. Following completion of the 12th interview it was agreed by the research team that the data collected was sufficient for the aims of the study and data saturation had been reached. Interviews took place between December 2020 and March 2021. All interviews were audio recorded. Recordings were initially transcribed using an online transcription service (otter.ie) and then verified by the research team to ensure accuracy.

Table 15: Veterinarian telephone interview schedule

Telephone interview questions
1. What do you think are the consequences of antimicrobial resistance?
2. Who do you feel is responsible for antimicrobial resistance?
3. What do you think are the **benefits** associated with reducing antimicrobial use on farms?
4. What do you think are the **risks** associated with reducing antimicrobial use on farms?
5. How do you view your professional responsibility towards antimicrobial use and antimicrobial resistance?
6. How would you describe your access to laboratory (susceptibility/diagnostic) testing?
7. How would you describe your access to training focused on antimicrobials?
8. Do you have access to peer support in relation to reducing antimicrobial use?
9. How do your superiors influence your prescribing behaviour, if at all?

10. What do you think your peer's views on antimicrobial use and antimicrobial resistance are?
11. Whose advice and opinion do you most respect around antimicrobial usage? And why?
12. What are your experiences of client pressure and prescribing treatment plans?
13. What do you think would help improve the relationship between farmers and veterinarians when it comes to reducing antibiotics?

5.2.3 Data analysis:

5.2.3.1 Online survey

All survey data was analysed using IBM SPSS Statistics version 25. Descriptive statistics (mean, SD, percentages) were used to explore individual level data. ANOVA, independent sample t-tests and Pearson's correlations were used to compare differences in responses amongst participants within the data.

ANOVA was used to test differences in responses between groups (age groups [18-39, 40-59, 60+ years] and years veterinary experience [less than 10 years, 10-19 years, 20-29 years, 30+ years]). Independent samples t-tests were used to test for significant differences between farmers from Northern Ireland compared with Republic of Ireland and different gender with regards to having stopped blanket use of antimicrobials. None of these tests resulted in any significant differences within the data, with the exception of Republic of Ireland veterinarians perceiving policies to restrict antibiotic use as more helpful as a strategy to promote responsible AMU than their NI counterparts).

5.2.3.2 Telephone interviews

Interview transcripts were imported into NVivo 12 (QSR International Pty Ltd, Doncaster, Victoria, Australia) software for qualitative analysis. To achieve data "immersion" and generate initial areas of interest within the data, the transcripts were read repeatedly. Codes were assigned freely from the data. Codes were then grouped, along with their related data into potential themes, identifying overlap and commonalities and where necessary themes were refined (I.e., collapsed or divided). At this stage transcripts were re-read to ensure no data had been missed in earlier coding stages. The identified themes and sub-themes were mapped to the COM-B model. In the final stages, transcripts were read again ensuring themes represented the data accurately and appropriate quotations were chosen to illustrate each theme and sub-themes.

Reflexivity relates to sensitivity to the ways in which the researcher and the research process may shape the data collected, including the role of prior assumptions and experience (Birks et al., 2014). As data was collected and analysed, ongoing discussions took place within the research team to ensure reflexivity within the qualitative research.

5.3 Findings

5.3.1 Online survey

5.3.1.1 Demographics

A total of 26 dairy veterinarians completed the online survey, the participants were made up of 17 males, 8 female and 1 veterinarian whose gender was not disclosed, all of whom were in full time employment. 16 of the participants were from Northern Ireland and 10 were from the Republic of Ireland. The veterinarians who completed the survey ranged in age, years of experience, role within practice and number of veterinarians in their practice. Table 16 below shows an overview of the demographic characteristics of the survey participants.

Table 16: Demographic characteristics of veterinarians who completed the online survey

Gender	Experience*	Role in practice	Number of vets in practice**
Male = 17	**<10 = 7**	**Practice owner/partner = 13**	**2-5 = 9**
Female = 8	**10-19 = 7**	**Employee = 10**	**5.5-10 = 9**
Other = 1	**20-29 = 6**	**Prefer not to say = 1**	**10.5-15 = 4**
	30+ = 6	**Other = 1 (Vet consultant)**	**15.5-20 = 3**
Age*	**Region**	**Employment status**	**Prefer not to say = 1**
18-39 = 11	**NI = 16**	**Full time = 26**	
40-59 = 11	**ROI = 10**		
60+ = 4			

**=Years, **0.5=part time, 1=full time. ROI=Republic of Ireland, NI=Northern Ireland*

5.3.1.2 Vet knowledge of antibiotics and AMR

The knowledge of the veterinarians about antibiotic use and AMR was very good with almost all answers answered correctly as shown in table 17.

Table 17: Veterinarian knowledge of antibiotic use and AMR.

	True	False
Antibiotics are used to cure infections caused by viruses	1 (3.8%)	25 (96.25)
Bacteria can become resistant to antibiotics when antibiotics are frequently used	25 (96.2%)	1 (3.8%)
Overuse of antibiotics can lead to antimicrobial resistance	26 (100%)	- -
Misuse of antibiotics can lead to antimicrobial resistance	26 (100%)	- -
Certain antibiotics are reserved for human use	26 (100%)	- -

5.3.1.3 Vets perceived ability and procedural knowledge of responsible antibiotic use

Veterinarians were asked to report how skilled they felt they were on a scale of 1 to 7 where 1=unskilled and 7=very skilled. The means ranged from 6.5000 to 5.5769, indicating that the veterinarians surveyed perceive themselves to be quite highly skilled in a range of antimicrobial prescribing related practices which can be seen in table 18 below.

Table 18: Veterinarians perceived ability and procedural knowledge of responsible antibiotic use

	1=Unskilled – 7=Very skilled	
	Mean	S.D.
I am able to calculate the correct dose of antibiotics for animals	6.5000	.64807
I am able to educate farmers on the use of alternative therapies to treat common diseases on their farm (e.g. vaccines, anti-inflammatories)	6.4231	.85665
I am able to calculate and administer the correct duration the antibiotics are used for	6.3846	.69725
I am able to comply to antibiotic protocols when treating animals	6.1923	1.05903
I am able to identify the correct antibiotic for infection.	6.0385	.82369
I am able to record relevant antibiotic usage information for each farm within my practice	5.7692	1.50486
I am able to monitor and record antibiotic use within my practice	5.5769	1.67745

5.3.1.4 Vet concern for AMR for humans and animals

Veterinarians were asked how concerned they were about antimicrobial resistance for humans and animals on a 7-point Likert scale where 1=not at all concerned and 7=extremely concerned. Veterinarians overall reported being slightly more concerned about AMR for humans than for animals (humans: M=6.077, SD=1.0554 and animals: M=5.577, SD=1.1721)

5.3.1.5 Vet intentions to use AMs responsibly.

Veterinarians were asked whether they agreed or disagreed with intentions relating to responsible AMU (1=strongly disagree, 7=strongly agree). The means ranged from 6.7692 to 5.4615, indicating good agreement amongst the veterinarians that the intentions in table 19 below related to themselves.

Table 19: Veterinarians reported intentions related to responsible AMU prescribing practices

	1=strongly disagree – 7=strongly agree	
	Mean	S.D.
I intend to encourage the implementation of alternative methods to using antibiotics e.g. use of vaccines and herd health planning	6.7692	.51441
I intend to use antibiotics responsibly in my practice	6.7308	.66679
I intend to reduce antibiotic use in my practice	6.0769	1.09263
I intend to adhere to antibiotic selection protocols and recommendations before prescribing antibiotics (e.g. susceptibility and diagnostic testing)	5.4615	1.10384

5.3.1.6 Vet responsible antimicrobial prescribing

Participants were presented with the following scenario: *"Frank is a vet, and his client is a dairy farmer getting ready to dry off his herd. Together with his client, they discuss the latest milk recordings for the herd. Only 7% of cows have high cell counts. Frank decides to prescribe the high*

cell count cows with dry cow antibiotic tubes and treat the remaining herd with a non-antibiotic teat sealant". Keeping this scenario in mind, veterinarians then indicated how often they made similar decisions to Frank in their practice.

On a scale of 1-7 (1=never, 7=always) the mean for making decisions similar to Frank i.e. only prescribing dry cow antibiotic tubes to cows with a high cell count, was 4.7692 SD=1.55712. 73% (n=19) of the veterinarians surveyed make decisions similar to Frank frequently, usually or always. While 27% (n=7) of veterinarians surveyed make decisions similar to Frank never, rarely, occasionally or sometimes.

Table 20: How often veterinarians surveyed make decisions similar to the Frank scenario

Never	Rarely	Occasionally	Sometimes	Frequently	Usually	Always
1 (3.8%)	3 (11.5%)	1 (3.8%)	2 (7.7%)	9 (34.6%)	9 (34.6%)	1 (3.8%)

5.3.1.7 Vet perceptions of strategies to promote more responsible AMU practices on dairy farms.

Veterinarians were asked to rate how helpful they felt particular strategies would be in helping to promote more responsible AMU on dairy farms. The complete findings are presented in table 21, the top 7 strategies reported by veterinarians were:

1. Provision of tailored herd health plans and routine visits for clients
2. Provide financial incentives or grants to support the use of alternatives to antibiotics such as herd health planning, vaccines etc.
3. Improve diagnostic and susceptibility testing procedures.
4. Mandatory antibiotic use recording for farms
5. Put in place new policies and regulations to restrict antibiotic use.
6. Provide educational training programs for all farmers on antibiotics and preventing infectious disease.
7. Provide training and support to improve communication skills of vets.

While compulsory CPD for veterinarians on antibiotic use and uncoupling veterinary prescribing from the sale of antibiotics were considered to be only moderately or not helpful at all according to the veterinarians within this survey. Table 21 below provides the mean for how helpful survey participants ranked the strategies.

Table 21: Perceived helpfulness of strategies to promote more responsible AMU on farm

	1=Not at all helpful	4= Moderately helpful	7=Very helpful
Provision of tailored herd health plans and routine visits for clients	M=6.3077		SD=.97033
Provide financial incentives or grants to support the use of alternatives to antibiotics such as herd health planning, vaccines etc.	M=6.1154		SD=1.21085

Improve diagnostic and susceptibility testing procedures	M=6.1154	SD=1.10732
Mandatory antibiotic use recording for farms	M=5.6923	SD=1.40767
Put in place new policies and regulations to restrict antibiotic use	M=5.6154	SD=1.47179
Provide educational training programs for all farmers on antibiotics and preventing infectious disease.	M=5.6154	SD=1.35873
Provide training and support to improve communication skills of vets	M=5.5769	SD=1.47440
Assign one contracted vet to a farm	M=5.5000	SD=1.94422
Mandatory antibiotic prescribing recording for veterinary practices	M=5.3462	SD=1.62339
Implement legal action should policies and legislation not be adhered to	M=4.7308	SD=2.27258*
Publish antibiotic usage data on each farm 3 times a year	M=4.6538	SD=1.87494
Compulsory CPD for veterinarians on antibiotic use.	M=4.3846	SD=1.81278
Uncoupling veterinary prescribing from the sale of antibiotics	M=1.5000	SD=1.27279

5.3.2 Telephone survey

5.3.2.1 Demographics

A total of 12 veterinarians whose work focused on dairy cattle were interviewed, this included 8 male veterinarians and 4 female veterinarians. The participants were equally split between Northern Ireland and the Republic of Ireland. All veterinarians worked in a full-time capacity, 9 were practice owners. Participants' age ranged from 28-65 years with between 3-43 years of experience working as a veterinarian. (Table 22)

Table 22: Characteristics of interview participants

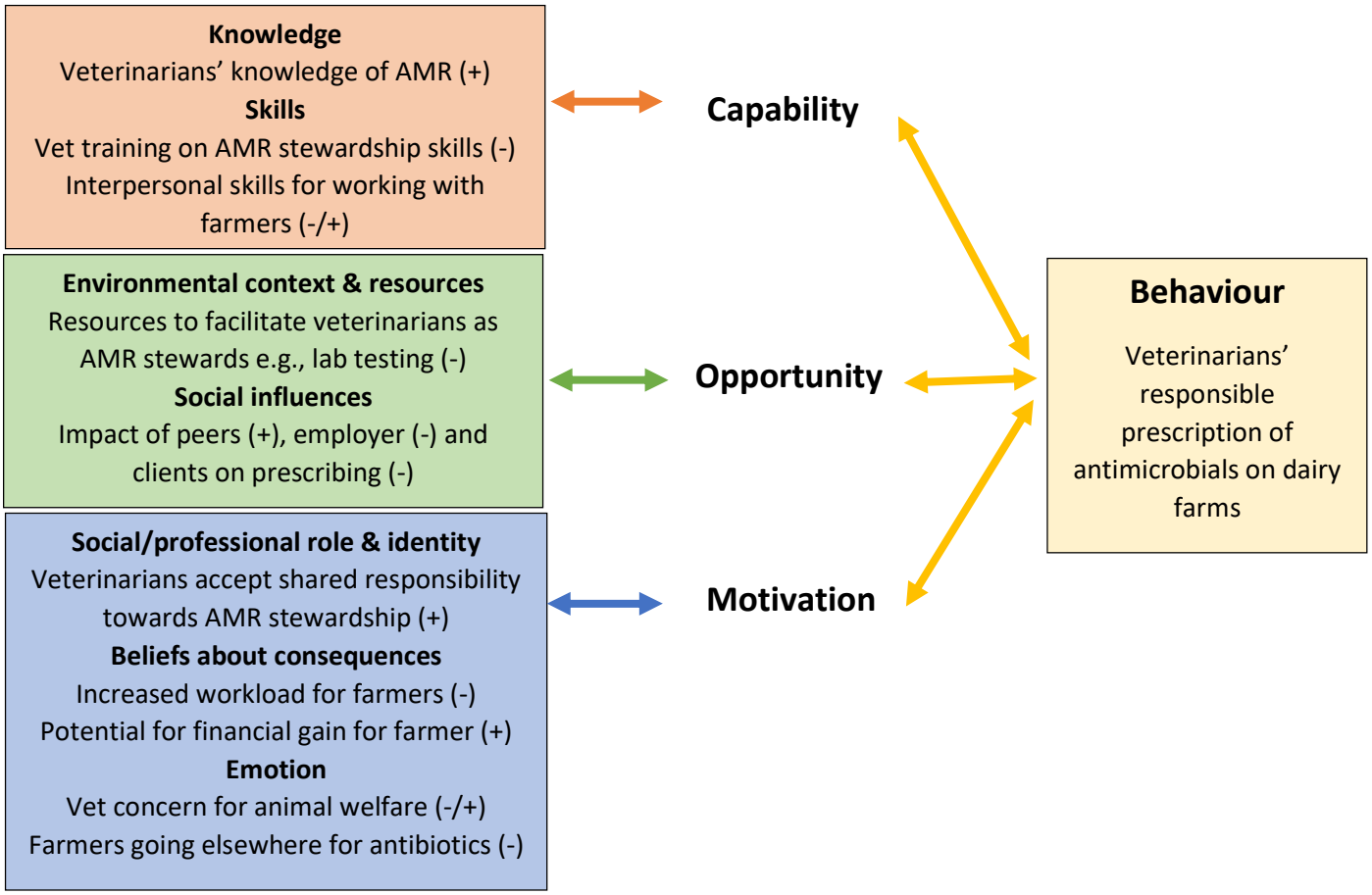
Veterinarian	Gender	Age*	Experience*	Region	Role	Employment status
Vet 1	Male	53	29	ROI	Practice owner	Full time
Vet 2	Male	65	43	ROI	Practice owner	Full time
Vet 3	Male	48	25	NI	Practice owner	Full time
Vet 4	Female	28	5	ROI	Employee	Full time
Vet 5	Male	55	32	NI	Practice owner	Full time
Vet 6	Female	35	12	ROI	Practice owner	Full time
Vet 7	Female	32	3	ROI	Employee	Full time
Vet 8	Male	62	42	ROI	Practice owner	Full time
Vet 9	Male	50	28	NI	Practice owner	Full time

Vet 10	Male	56	28	NI	Employee	Full time
Vet 11	Female	58	35	NI	Practice owner	Full time
Vet 12	Male	52	29	NI	Practice owner	Full time

*Years, ROI=Republic of Ireland, NI=Northern Ireland

5.3.2.2 Mapping of interview findings to COM-B model

Findings of this study provide an insight into veterinarians' views on achieving responsible AMU on dairy farms. Figure 6 shows the factors influencing veterinarian's responsible antibiotic prescribing behaviour. Seven of the 14 TDF domains (knowledge; skills; social/professional role and identity; beliefs about consequences; environmental context and resources; social influences; emotion) were identified and mapped to the COM-B elements.



Note: Barriers (-) and facilitators (+) that influence responsible antimicrobial prescription and antimicrobial stewardship efforts

Figure 6: Combined COM-B & TDF analysis of influencers on veterinarians' prescription of antimicrobials on dairy farms

The capability factors influencing responsible AM use included veterinarian knowledge of AMR and their ability to influence farmer behaviour. Further, opportunity factors influencing responsible AMU were resources to facilitate responsible antimicrobial prescription by veterinarians and social

influences on their prescribing. The motivation factors included veterinarian decision making, beliefs about the consequences of AMR and veterinarians' professional role in reducing AMU.

5.3.2.3 Veterinarians' capability to promote reduced AMU/act as AMR stewards

Veterinarian and farmer AMR knowledge

Participating veterinarians have a good knowledge of the risks associated with AMR and the potential consequences in the future for both human and animal health if changes are not made to current practices. There is an understanding amongst participants that the development of AMR can lead to treatment failures down the line.

"Antibiotics aren't going to work for treatment for certain diseases. As time goes on it has developed, and there could be some serious diseases that we're not going to be able to really cure because the antibiotics aren't working" (Vet 11).

Participants also believe that farmers being educated about the risks associated with AMR is fundamental to achieving reduced AMU on farms. Veterinarians felt that it is important for farmers to understand the risks associated with AMR as well as the positive consequences of reducing AMU on farms as a way of motivating and encouraging farmers to make changes to their current practices.

"I think farmers need to be hearing about reducing antibiotics from other sources, and maybe hearing about the positive aspect of it" (Vet 6).

Many veterinarians in this study believed that they would benefit from additional training on AMR as well as AMR stewardship. Many felt that their access to training on AMR and reducing AMU could be improved with some also suggesting mandatory education for both farmers and veterinarians surrounding the topic of AMR.

"There has been plenty of CPD available about AMR and Antimicrobial Use in recent years. But my opinion is the uptake among my professional colleagues has been reasonably poor" (Vet 9).

"Vets could do with more training, and it should be mandatory training on antibiotics" (Vet 8).

5.3.2.4 Veterinarians' opportunity to promote reduced AMU/act as AMR stewards

Resources to facilitate veterinarians AMR stewardship

Many participating veterinarians want to be able to use susceptibility testing prior to prescribing antibiotics to minimise the chances of AMR and treatment failure. However, the time delay for getting the results is the biggest drawback that participants associate with such testing. Although it does not fully discourage them from using the tests, often antibiotics are prescribed anyway before the results are back.

"It would definitely be, in theory, very beneficial. In practice, it can be very slow to get results back. So, by the time we get results it's probably too late for that particular case, but it's just if you had a farm where you'd, you know, maybe an outbreak of disease where it's more than one animal becoming ill, it would be helpful for maybe the second animal that becomes ill" (Vet 11).

Participants reported that more rapid testing methods which can be used on farm would enable them to make more effective use of susceptibility and diagnostic testing and ensure the correct antibiotic is given to animals as soon as possible.

"Whether we do really need to use culture and sensitivity, in the absence of treatment failure, you know, that as a routine, I find that probably a lot more difficult to implement, basically, because of the timing involved in getting the results, you know, so development of, say, you know, I want to say animal side, or near enough animal side testing for culture and sensitivity would be more than welcome" (Vet 10).

Social influences on veterinarian prescribing

Participating veterinarians claimed that peers, authoritative figures, and clients influence their decision to prescribe antibiotics in some manner or form.

"If there are vets that I feel have the same values as me, I would respect their theories and opinions and take on their techniques and advice on board" (Vet 4).

Many reported that they take on board the experiences other veterinarians have with particular treatments and will feel more confident in making similar decisions based on the success of their peers.

"It's really more you know if somebody had used a particular drug on a particular farm and said, look, I used drug X and it worked very well in this situation that would be more of a scenario where a roundtable discussion is what works for a particular farmer" (Vet 12).

Profit from the sale of antibiotics does not motivate participating veterinarians within this study on an individual level to prescribe AM to farmers. However, some noted that they felt pressure from their employers to prescribe antibiotics for financial gain.

"There is a mark-up on selling antimicrobials you to make more drug sales, so I can understand how they can get a little bit twisted into that, like for me I have a salary, I definitely take the financial side. But to be fair I try to hit back now, I won't sell antibiotics if I know it is not ok, it really bothers me." (Vet 4).

Some participants felt pressure from farmers to prescribe antibiotics they requested. Farmers believe they know what their animals need based on previous experience and there is a need for farmers to be educated in order to be more open to changing their practices.

"Dairy farmers, they are exceedingly aggressive at wanting the antibiotic they want, and they insist that they're professional enough to know what antibiotic is needed on their farm" (Vet 2).

"I would have problems with persuading farmers to go another way… I think health plans, and talking to a farmer beforehand, and prescribing vaccinations, and different preventative measures, but it's very difficult to get them into that mode. They'll do it if you do it for free, but for us to charge to go out and do a health plan, they really don't want to do that" (Vet 11).

Participants believed that they have some influence over what farmers do and put this down to effective communication with their clients. They felt that by working together with farmers they are able to make changes to on-farm practices.

"*I definitely think opening the communication between farmers and vets is important, we make plans together. We can talk things through together"* (Vet 7).

Many participating veterinarians perceive that farmers have more trust in veterinarians who are more experienced than those who are relatively new to the profession. Some believe that farmers are unlikely to trust in or take on board the advice they get from less experienced veterinarians or those who easily back down when pressured.

"I can absolutely guarantee you, there will be young vets today who have gone out this morning to a farmer, the farmer's telling them what to do and they don't have the confidence to stand up" (Vet 1).

5.3.2.5 Veterinarians' motivation to promote reduced AMU/act as AMR stewards.

Veterinarian decision-making influences

Many participating veterinarians said that farmers have access to antibiotics outside their practice and this hinders their role as AMR stewards. Many were concerned that if they do not prescribe antibiotics when a farmer requests them that they will go elsewhere and get the antibiotics from another source.

"I do have a concern going forward that there seems to be an awful lot more online pharmacies, people prescribing, and you know dispensing carryon, online and so on. And I just worry that we're just getting too far away from the vet that actually knows the farm who's doing the prescribing" (Vet 12).

Veterinarians within this study see it as their role to assess animals under their care before prescribing antibiotics with many suggesting that a one-farm-one-veterinarian policy would be advantageous to reducing AMU on farms. Veterinarians gain an understanding of the situation on the farms they deal with and therefore see themselves as having the ability to play a pivotal role in controlling AMU on their farms.

"We'd need a very pivotal role on it, of a vet, but really, we should be controlling. The law is that people shouldn't be, you know, we prescribe antibiotics to animals under our care. So, we should be seeing the animal, treating it, or advising the farmer, and we would have a very close relationship with our farmers. We're there regularly. We know their farms, and we know the personalities, and we know their strengths and weaknesses. So, we're the perfect person to control the antibiotic usage on that farm. Recently, in recent years, it's gone a wee bit out of our control. Farmers find medicines elsewhere" (Vet 11).

Animal welfare is a priority for participating veterinarians and is one of the greatest influencers of their decision to prescribe antibiotics. Many have concerns that if the use of antibiotics is too tightly restricted on farms, then ultimately the welfare of the animals who need antibiotic treatment will suffer.

"That would be my biggest concern that they just make it too draconian that ironically the animal welfare could suffer" (Vet 12).

Beliefs about consequences of reduced AMU

Participants associate reduced AMU on farms with both positive and negative consequences. They are aware of the need to preserve antibiotics to prolong their effectiveness to treat both humans and animals.

"Antibiotics are a limited resource. And, you know, we do need to preserve their use, you know, as I said before, both in animal and the human health because there's not going to be an unlimited supply, you know, and once resistance sets in it is extremely hard to reverse" (Vet 10).

On the other hand, some veterinarians in this study believe reducing AMU on farm would come with challenges and require farmers to make changes to their farm structures and hygiene practices to overcome this in order to prevent disease spread and animal suffering.

"There are things that can be difficult to control without antibiotic usage. Probably what we need to encourage farmers to do more is improve their hygiene, and biosecurity, and vaccination" (Vet 11).

Participants also felt that if a farmer makes improvements to his/her farm management while reducing AMU there should be a financial gain for the farmers from a business point of view. Animals will be less susceptible to disease and therefore be healthier and more productive, and farmers will spend less money on antibiotics.

"There is a business sense there for the farmer, if he does have an animal that does require intensive antibiotic treatment then it is more likely to work because he hasn't used it before or extensively before" (Vet 3).

Veterinarians' professional role in reducing AMU

Veterinarians in this study accept that they are responsible for taking action to reduce AMR. They agree that this responsibility is shared and rather than placing the blame on one individual stakeholder they are aware that anyone involved in the development, prescription or use of antibiotics, both in human and animal medicine, are responsible.

"I think everybody that uses them are. So most of the people that prescribe them doctors and vets, and also people who use them as farmers, or, or human patients, because I think they do put a lot of pressure on prescribers as well which isn't fair. So they need to be educated enough" (Vet 4).

5.3.3 Potential behaviour change interventions to promote more responsible prescribing of antimicrobials amongst dairy veterinarians.

As outlined in section 2.4.2, the BCW can be used to identify intervention functions and policy categories which are more likely to result in successful behaviour change interventions. The factors influencing dairy veterinarians antimicrobial prescribing practices and stewardship efforts, were linked to intervention functions and policy categories in this manner. Table 23 below provides an overview of this, with some potential behaviour change interventions proposed which will be discussed further at the end of the following section.

Table 23: Mapping the COM-B components influencing veterinarians antimicrobial prescribing practices to potential intervention functions and policy categories.

Influencer	**COM-B component**	**TDF**	**Intervention functions**	**Policy categories**	**Potential behaviour change intervention**
Desire for more veterinary training around AMR and encouraging farmer behaviour change	Capability – physical	Physical skills	Training	Guidelines Fiscal measures Regulation Legislation	Vet training to enable education of farmers on AMR and encouraging farmer behaviour change
Peers and clients as an	Opportunity - social	Social influence	Restriction Environmental	Communication/ marketing	Vet peer information

influencer of prescribing practices			restructuring Modelling Enablement	Guidelines Fiscal measures Regulation Legislation Environmental/ social planning Service provision	sharing groups to share knowledge and experiences of working with farmers to successfully reduce AMU on farms
Provision of efficient testing for antimicrobial susceptibility testing	Opportunity - physical	Environmental context & resources	Training Restriction Environmental restructuring Enablement	Guidelines Fiscal measures Regulation Legislation Environmental/ social planning Service provision	Provide rapid susceptibility and diagnostic testing for dairy cattle
Veterinarians concern for animal welfare and losing clients if AM prescription is reduced	Motivation – reflective	Beliefs about consequences	Education Persuasion Modelling	Communication/ marketing Guidelines Regulation Legislation Service provision	Collaborative farmer and veterinarian workshops to understands each other's responsibilities and roles when it comes to responsible AMU

5.4 Discussion

This study explored veterinarian's antimicrobial prescribing behaviour on dairy farms using the COM-B model for the first time. Various factors were found to influence veterinarians' responsible antimicrobial prescribing practices. In line with the COM-B model, influencing factors included both individual cognitive and motivational factors as well as external social and physical factors.

The findings illustrate the complexity of veterinarians' behaviour surrounding responsible antimicrobial prescribing to dairy cattle. Factors identified as influencing veterinarians' capability, opportunity and motivation to prescribe antimicrobials responsibly included AMR knowledge and access to training (capability), resources to facilitate AMR stewardship and social influences including peers, clients and employers (opportunity), concern for animal welfare, losing clients, beliefs about the consequences of AMR and veterinarians' professional role in reducing AMU (motivation).

Capability reflects veterinarians' psychological and physical ability to engage in behaviour promoting reduced AMU on farm. Knowledge of AMR was identified as an influencer of the capability of veterinarians to engage in AMU-reducing behaviours and there was a desire amongst veterinarians for more training and education surrounding AMR and AMR stewardship.

The findings of this study echo those of a recent survey of veterinarians in Kentucky, USA, which concluded that they would benefit from continued professional education to help improve prescription practices (Odoi et al., 2021). In order to overcome this barrier additional training or the introduction of more continuous mandatory training for both farmers and veterinarians on AMR and how to reduce AMU would be beneficial. Interventions to increase effective prescribing in human healthcare such as educational interventions have previously improved clinical outcomes (Davey et al. 2017), which could be promising if applied effectively to veterinarians. It is important that continuous education programs are implemented for veterinarians on AMR to enhance all-round knowledge and improve their advisory skills (Bazzi et al., 2022).

Objective one of the Global Action Plan on antimicrobial resistance is to improve awareness and understanding of AMR through effective communication, education, and training (WHO, 2015a). Based on the intervention functions of the BCW, education and training can be useful to ensure veterinarians have adequate knowledge and awareness of AMR and the positive consequences of reducing AMU, which they can then pass on to their farming clients (Michie et al., 2014).

The study results suggest that behaviour change interventions should focus on continuous training of veterinarians on AMR as well as alternatives to prescribing antimicrobials as it may improve veterinarian's ability to educate farmers and encourage farmer behaviour change, increasing veterinarian's capability to achieve responsible antimicrobial prescribing. For example, annual or bi-annual training could keep the importance of prudent AMU at the forefront of veterinarians' minds and empower them to promote more responsible AMU on dairy farms.

Opportunity reflects external factors which influence veterinarians' willingness or capacity to engage in behaviour promoting reduced AMU on farm. Opportunity can be physical, based on environmental contexts and resources, or social, based on social interactions and influences. Resources to facilitate AMR stewardship (laboratory testing) and social influences including peers, clients and employers influenced veterinarians' opportunity to engage in responsible prescribing practices in this study.

As with this study, the need to improve sensitivity testing and services to promote increased uptake amongst veterinarians has been reported previously, with the availability of rapid and cheaper testing highlighted as the key factors (De Briyne et al., 2013). Lack of access to rapid and affordable diagnostic tests was also reported as a barrier to appropriate antibiotic prescribing by veterinarians in Australia (Norris et al., 2019). The development of more affordable and timelier diagnostic and susceptibility testing could improve veterinarians' use of such tests, enable the prescription of suitable antibiotics, and help slow the development of AMR. User-centred development of on-farm

diagnostic technologies is an area of research that will likely help catalyse significant behaviour change in the future.

Veterinarians are known to be influenced by their peers who play an important role in the decision-making process for antimicrobial prescription (Proctor et al., 2011; Vandeweerd et al., 2012). Veterinarian peer support groups could help contribute to veterinarians' intention to change their behaviours and promote reduced antibiotic prescription (Pucken et al., 2019).

Client expectation has previously been reported as a barrier to antimicrobial stewardship amongst Australian veterinarians (Hardefeldt et al., 2018). Relationships with clients was also reported as a major influence on prescription decision-making for pig veterinarians (Coyne et al., 2014; Coyne et al., 2016), sheep and beef veterinarians (Doidge et al., 2019) and cattle veterinarians (Gibbons et al., 2013). It has previously been suggested that veterinary peer support groups could strengthen veterinarian relationships with farmers which could help less experienced veterinarians as it can be difficult to gain farmer confidence (Higgins et al., 2017).

This suggests that behaviour change interventions should take into consideration the various social influences on veterinarian prescribing behaviour. Utilising the intervention function of modelling, based on the BCW, veterinarians can learn from and positively influence the behaviour of their peers. For example, information-sharing opportunities for experienced veterinarians to share how they handled certain clinical situations, particularly those which may have involved a difficult client may help improve veterinarians' confidence in their knowledge and decision making and minimise the effect of client pressure.

Companion animal veterinarians have previously reported commercial pressures to prescribe antibiotics to pet owners in order to retain clients (Smith et al., 2018), similar to pressure some veterinarians within this study felt from their superiors. A study of Australian doctors, dentists and veterinarians exploring the opportunities and challenges to improving antibiotic prescribing practices reported that pressure from supervisors or colleagues to prescribe antibiotics was not perceived as a barrier (Zhuo et al., 2018). Similarly, a study exploring the factors influencing the antibiotic use behaviour of Australian veterinarians reported colleague pressure to prescribe antibiotics as "not" or "somewhat" a barrier to responsible antibiotic prescribing practices (Norris et al., 2019).

This suggests that some focus should be given to the expectation veterinary employers have when it comes to prescribing of antibiotics. Some practice owners may benefit from further education on the need to reduce antibiotics, perhaps highlighting the potential financial benefits of sales of

vaccination to prevent disease as opposed to sales of antibiotics to treat diseases while helping to slow the emergence of AMR. Additionally, placing restrictions on the ability of veterinary practices to make a profit from antimicrobial sales may minimise the pressure reported by a small number of veterinarians within this study. It is important that everyone within a practice is on the same page and aware of their responsibility to prescribe antimicrobials responsibly.

Motivation reflects the brain processes which energise and direct behaviour. Motivation can be automatic, based on emotions or impulses, or it can be reflective as a result of evaluations and plans. Veterinarian concerns for animal welfare and losing clients if antimicrobials are not prescribed, their beliefs about the consequences of AMR and their acceptance of their professional role in reducing AMU were all found to influence veterinarians' motivation to engage in responsible AMU practices in this study.

The conflict of interest for veterinarians between prioritising responsible antimicrobial prescription and losing clients has been reported previously (Higgins et al., 2017; Norris et al., 2019). It has been recommended that veterinarians need to unite and work together (Tisdall et al., 2016). For example, if all veterinarians advise selective dry cow therapy, farmers will be unable to contact another veterinarian in regard to blanket dry cow therapy and therefore the risk of losing clients is avoided (Higgins et al., 2017). Based on the BCW it can be recommended that building better farmer and veterinarian relationships to promote a transparent working relationship may reduce the likelihood of farmers seeking antimicrobials elsewhere. This may be achieved through collaborative farmer and veterinarian workshops so that each stakeholder understands each other's responsibilities and roles when it comes to responsible AMU and what barriers each are trying to overcome to achieve this common aim.

Concern for the role of veterinary AMU in the development of AMR in humans has also been reported as an enabler of antimicrobial stewardship amongst Australian veterinarians (Hardefeldt et al., 2018). Again, promoting collaboration between veterinarians and farmers to work towards the shared goal of responsible antimicrobial use in dairy cattle may improve veterinarians' motivation to change their behaviour and prescribe antimicrobials more responsibly.

Concern for animal welfare as a barrier to reduced AMU was reported in this study and is also commonly reported in previous literature. UK veterinarians were concerned that reduced AMU could inhibit their ability to treat sick animals and maintain animal welfare (Golding et al., 2019) while Dutch veterinarians were unsure whether a sick animal would recover without antibiotics (Scherpenzeel et al., 2018). Herd health management and improved biosecurity have been seen previously as a cost effective and feasible approach to disease prevention as opposed to relying on

antibiotics (Postma et al., 2015; Rojo-Gimeno et al., 2016). As previously mentioned, some veterinarians would benefit from more education in relation to AMR. It can be recommended to policy makers that continuous training for veterinarians on alternatives to AMU and how to encourage uptake amongst their clients may help overcome this barrier and reassure veterinarians that it is possible to maintain animal welfare while prescribing antimicrobials responsibly.

The adoption of the COM-B model in this study has provided a better understanding of the underlying mechanisms which influence dairy veterinarians' behaviour relating to antimicrobial prescribing. It has highlighted what influences veterinarians' capability, opportunity, and motivation to prescribe antibiotics responsibly. More importantly, and unlike much other research in the field, it has linked current barriers and enablers of responsible antimicrobial prescribing, to identify which type of interventions in theory should be useful for promoting responsible prescribing by veterinarians to dairy cattle in the future.

Strengths and limitations

To the best of the authors' knowledge this is the first time the COM-B model has been applied to veterinarians' behaviour relating to responsible antimicrobial prescribing using a qualitative interview method. The findings highlight the usefulness of the COM-B model and its applicability to this area of research despite the potential limitations of this model (7.5.2). The use of the COM-B model in this area has laid the foundations for behaviour change interventions which can be linked to psychological theory to promote more responsible prescribing of antibiotics to dairy cattle by veterinarians. AMR is currently a very topical global health issue and therefore interview responses and findings may be subject to aspects of social desirability as it relied on participants to be honest and report their behaviours and opinions accurately. Additionally, the current studies recruited dairy veterinarians from the Island of Ireland and so findings may not be fully generalizable to different agricultural sectors and countries. Further research with veterinarians is warranted to triangulate these findings or identify additional barriers and facilitators.

5.5 Conclusion

This study used the COM-B model of behaviour to identify the factors which may influence responsible prescription of antimicrobials by dairy veterinarians. The barriers and facilitators identified as influencing veterinarians' *capability*, *opportunity* and *motivation* to responsibly prescribe antimicrobials to dairy cattle form the basis for a number of practical recommendations which can be considered by veterinarian advisory and policy-making teams. Applying behavioural frameworks to understand barriers and facilitators to veterinarians' antimicrobial stewardship efforts has revealed opportunities for empowering veterinarians' involvement in supporting

responsible antimicrobial use in dairy farming settings. This study identified the challenges faced by veterinarians which included lack of training to encourage farmer behaviour change, issues with laboratory testing, pressures from farmer clients and sometimes employers to prescribe antimicrobials against their better judgement, and concern for the perceived negative consequences of not prescribing antimicrobials such as animal welfare and farmers going elsewhere for prescriptions. Veterinarians having a good knowledge of AMR and the risks it can pose, veterinarian peers as a source of prescribing advice, the potential financial benefits for farmers as a result of reduced antimicrobial costs and the fact that veterinarians accept a shared responsibility for AMR all facilitate veterinarians in their role as antimicrobial stewards. This study has positive implications for policy makers and advisors, it is recommended that future antimicrobial stewardship interventions for dairy antimicrobial use should consider the factors and recommendations identified in this study.

5.6 Chapter 5 summary

This chapter provided an overview of the factors which influence veterinarians' efforts to prescribe antimicrobials responsibly on dairy farms. Veterinarian interview transcripts were analysed using the COM-B model of behaviour change to determine current barriers to responsible prescribing and identify behaviour change interventions which may help overcome the obstacles currently faced.

6. Chapter 6: Facilitated discussion workshop with stakeholders in the NI dairy industry to test the feasibility of proposed behaviour change interventions to encourage responsible AMU on NI dairy farms (*study 3*)

Study 3: Abstract

In order to assess the feasibility of the interventions proposed to overcome barriers to responsible AMU from chapters 5 and 6, a multi-stakeholder workshop comprised of dairy farmers, dairy farm advisors, dairy technologists and a veterinarian was conducted. Previous study findings were disseminated to the group followed by participants individually rating the 10 proposed behaviour change interventions. Then participants took part in a facilitated discussion on their reasoning for their ratings. The APEASE criteria for behaviour change interventions was used by participants to assess each of the interventions, this included acceptability, practicability, effectiveness, affordability, side effects and equity. The discussion focused on the perceived advantages and disadvantages of each intervention, how problems could be overcome and which interventions they felt should be prioritized. Farmer education programmes to improve awareness of their role in AMR, farmer peer information sharing groups for farmers to share experiences of reducing AMU successfully with their peers and encourage others to act, training to impart skills needed by farmers to reduce AMU while maintaining herd health and productivity and positive reinforcement and feedback programs to build farmers confidence in their ability to reduce AMU safely on their farms were the behaviour change interventions which were most favoured by workshop participants as feasible methods of promoting responsible AMU amongst dairy farmers. Whilst veterinarian peer information sharing groups where veterinarians can share knowledge and experiences of working with farmers to successfully reduce AMU on farms and veterinarian training to enable them to educate farmers on AMR and help encourage farmer behaviour change were also well received amongst the participants of the workshop as behaviour change interventions aimed at promoting more responsible antimicrobial prescribing by veterinarians. The involvement of relevant stakeholders in the co-development of interventions helps to maximise the success rate of behaviour change interventions.

6.1 Introduction

In order to assess the feasibility of the behaviour change interventions proposed based on the results written in chapters 5 and 6, a multi stakeholder workshop was organised. The workshop provided an opportunity for research findings to be disseminated to key members of the NI dairy

industry. Various representatives from the NI dairy sector were invited to attend including dairy farmers, veterinarians, farm advisors, dairy technologists, and processor representatives.

The participation of different stakeholders in intervention planning can help to increase its fit with real world conditions (Bisset & Potvin, 2007; Bisset et al., 2009). New integrated approaches have emerged that enable the identification and combination of the expertise of multiple stakeholders in the development of systems approaches (Rütten et al., 2019). Importantly, these human-centred approaches focus on outcomes that enthuse, incentivise, and build on the strengths of all stakeholders (Chan, 2018). One common approach - experience-based co-design - has been widely used to create systems change in emergency medicine and mental health care settings (Donetto, Tsianakas & Robert, 2014; Mulvale et al., 2019). The contributions from stakeholders in the development of behaviour change interventions are key to ensure that views from those who will use the intervention in the real world have been included to maximise the likelihood of success at implementation (Faija et al., 2021). There is a need for researchers to move beyond push approaches and co-develop interventions with multiple stakeholders (Rütten et al., 2019).

The aim of the workshop was primarily to have participants rank ten proposed behaviour change interventions against the APEASE criteria (Michie et al., 2014). The APEASE criteria is a checklist of considerations when selecting intervention content and mode of delivery, is it; **A**cceptable (is it acceptable to those delivering, receiving and commissioning it?), **P**racticable (can it be delivered to scale?), **E**ffective (cost-effective (is there evidence it is likely to be (cost)effective?), **A**ffordable (can it be delivered to budget?), are there any **S**ide-effects/Safety issues? is their **E**quity (that is does it disadvantage any groups?) (Atkins et al., 2020). The average ratings can provide an indication as to whether any given intervention or intervention component stands out as particularly strong or weak and the range can be used to assess the level of agreement (West et al., 2019). These APEASE criteria are used in stakeholder discussions to determine which behaviour change interventions are most feasible thereby generating a priority list of behaviour change interventions (Atkins et al., 2020).

Following the individual ratings of the interventions against the APEASE criteria, participants took part in a group discussion. The discussion focused on the advantages and disadvantages of each proposed intervention, allowed stakeholder to propose solutions to overcome barriers to implementation and also highlighted which interventions participants felt should be prioritised to help promote more responsible AMU on dairy farms.

6.2 Method

Following analysis of data collected from dairy farmers using online surveys and dairy veterinarians using one-to-one telephone interviews, a feedback workshop was organised for stakeholders from a range of disciplines within the dairy sector. Participants (n=10) included dairy farmers, farm advisors, dairy technologists/processors, and a veterinarian.

6.2.1 Ethics

The necessary ethical approval was granted for this study from Queen's University Belfast School of Biological Sciences Research Ethics Committee (MHLS 22_73). Participants were informed prior to taking part that all study information would be kept confidential; they were also made aware that they could withdraw from the study within two weeks following the workshop. Participants were asked to create a unique study ID number only identifiable to the main researcher to enable the withdrawal of data should they wish to do so.

6.2.2 Recruitment

As a result of time constraints, it was not feasible to hold workshops with stakeholders from both Northern Ireland and Republic of Ireland dairy sector and so this study provided a pilot view of how further research could be conducted in other regions including the Republic of Ireland.

Recruitment was aided by DAERA (Department of Agriculture, environment and rural Affairs, Northern Ireland). The workshop was aimed at stakeholders within the Northern Ireland stakeholders including farmers, veterinarians, farm advisors, policy advisors, dairy processors and technologists. A representative from DAERA recruited appropriate stakeholders by informing them of the location and date of the workshop and those who were available to attend contacted the PhD to confirm their attendance.

6.2.3 Procedure

The workshop was held at CAFRE Greenmount Campus on the 26$^{th\ of}$ July 2022. Participants were presented with the findings of previous studies within the wider research project and were informed of the behaviour change interventions proposed from these findings to promote responsible antimicrobial use on dairy farms. Following the presentation, participants were asked to individually evaluate the proposed interventions using the APEASE criteria (affordability, practicability, effectiveness/cost-effectiveness, acceptability, side-effects/safety, equity) for behaviour change interventions (Table 24). Interventions were considered using the APEASE criteria to identify which are most appropriate within the context of promoting responsible AMU on farms and therefore most likely to be implemented and have an impact.

Table 24: APEASE criteria for behaviour change interventions

Acceptability	How far is it acceptable to key stakeholders? This includes the target group, potential funders, practitioners delivering the interventions and relevant community and

(0-10)	commercial groups.
Practicability (0-10)	Can it be implemented at scale within the intended context, material and human resources? What would need to be done to ensure that the resources and personnel were in place, and is the intervention sustainable?
Effectiveness (0-10)	How effective is the intervention in achieving the policy objective(s)? How far will it reach the intended target group and how large an effect will it have on those who are reached?
Affordability (0-10)	How far can it be afforded when delivered at the scale intended? Can the necessary budget be found for it? Will it provide a good return on investment?
Side Effects (-5-+5)	What are the chances that it will lead to unintended adverse or beneficial outcomes?
Equity (-5-+5)	How far will it increase or decrease differences between advantaged and disadvantaged sectors of society?

Participants were then split into two groups (5 participants per group). Each group had two researchers present, one to facilitate the discussion and one to take notes during the discussion. (Assistance was provided by members of the QUB AMR research team – TB, CMcK and LG). Participants discussed in groups each of the proposed interventions. For each intervention participants were asked about the benefits and drawbacks, how any perceived barriers to implementation may be overcome and finally which of the interventions they felt should be a priority to help tackle imprudent AMU on dairy farms. (Appendix 4c shows the discussion guide used by facilitators during these discussions).

6.2.4 Data analysis

Participant discussions were audio recorded in addition to notes being taken. Audio recordings were transcribed so as to write up the findings of the workshops. Average ratings were determined for each of the 10 proposed intervention options to identify which were perceived as the most feasible. Points made by participants during the facilitated group discussion will be used to illustrate the reasoning behind APEASE ratings.

6.3 Findings

6.3.1 APEASE Rating of behaviour change interventions

10 stakeholders rated behaviour change intervention options using the APEASE criteria (dairy farmers n=3, dairy advisors n=4, dairy technologists n=2 and veterinarian n=1). The group was made up of 2 females (n=1 veterinarian, n=1 farm advisor) and 8 males (remaining participants). The average APEASE ratings given to each of the proposed behaviour change interventions to promote more responsible use of antimicrobials on dairy farms can be seen from table 25 below.

Table 25: Mean ratings given by participants for each behaviour change intervention

Intervention	**Acceptability**	**Practicability**	**Effectiveness**	**Affordability**	**Side effects**	**Equity**	**Total mean score**
Farmer Education programme to improve awareness of their role in AMR	7.7	7.7	6.3	7	3.2	2	33.9
Training to impart skills needed by farmers to reduce AMU while maintaining herd health and productivity	7.7	7	7.1	6.4	3	2.2	33.4
Farmer peer information sharing groups for farmers to share experiences of reducing antibiotic use successfully with their peers and encourage others to act	8.4	7.3	7.4	6.7	2.2	1.5	33.5
Positive reinforcement & feedback programs to build farmers confidence in their ability to reduce AMU safely on their farms	7.9	6.9	6.4	6.2	2.3	2	31.7
Vet training to enable them to educate farmers on AMR and help encourage farmer behaviour change	7.4	6.7	7	6.3	2.3	1	30.7
Mandatory vet training on AMR and how to reduce the need for use on dairy farms	6.2	6.1	6.3	5	2.2	1.5	27.3
Legislation/guidelines for one vet per farm at any one period of time for antimicrobial	6.1	4.9	5.7	5.6	1	0.1	23.4

prescriptions							
Removal of profit from veterinary antimicrobial sales	3.9	3	4.2	3.9	-1.2	-0.4	13.4
Provide rapid (potentially on farm) susceptibility and diagnostic testing for dairy cattle	6.7	4.8	7.2	3.7	1.8	1.5	25.7
Vet peer information sharing groups where veterinarians can share knowledge and experiences of working with farmers to successfully reduce AMU on farms	7.9	6	7.2	6.8	2.5	1.9	32.3

The behaviour change interventions rated best on average overall relating to farmers AMU were; farmer education programme to improve awareness of their role in AMR (33.9/50), farmer peer information sharing groups for farmers to share experiences of reducing antibiotic use successfully with their peers and encourage others to act (33.5/50), training to impart skills needed by farmers to reduce AMU while maintaining herd health and productivity (33.4/50) and positive reinforcement & feedback programs to build farmers confidence in their ability to reduce AMU safely on their farms (31.7/50).

Veterinarian peer information sharing groups where veterinarians can share knowledge and experiences of working with farmers to successfully reduce AMU on farms (32.3/50) and veterinarian training to enable them to educate farmers on AMR and help encourage farmer behaviour change (30.7/50) were also well received amongst the participants of the workshop as behaviour change interventions aimed at promoting more responsible AM prescribing by veterinarians.

Mandatory veterinarian training on AMR and how to reduce the need for use on dairy farms (27.3/50), providing rapid (potentially on farm) susceptibility and diagnostic testing for dairy cattle (25.7/50) and legislation/guidelines for one veterinarian per farm at any one period of time for antimicrobial prescriptions (23.4/50) were relatively well rated but not the most favoured interventions by participants.

Removal of profit from veterinary antimicrobial sales (13.4/50) was the least well received of the behaviour change interventions proposed to participants.

Table 26 below highlights which of the interventions on average were rated highest and lowest against the 6 APEASE criteria items (affordability, practicability, effectiveness/cost-effectiveness, acceptability, side-effects/safety, equity).

Table 26: highest and lowest ranking interventions for each of the items within the APEASE criteria.

A	*Most acceptable*	Farmer peer information sharing groups for farmers to share experiences of reducing antibiotic use successfully with their peers and encourage others to act (8.4/10)
	Least acceptable	Removal of profit from veterinary antimicrobial sales (3.9/10)
P	*Most practical*	Farmer Education programme to improve awareness of their role in AMR (7.7/10)
	Least practical	Removal of profit from veterinary antimicrobial sales (3/10)
E	*Most effective*	Farmer peer information sharing groups for farmers to share experiences of reducing antibiotic use successfully with their peers and encourage others to act (7.4/10)
	Least effective	Removal of profit from veterinary antimicrobial sales (4.2/10)
A	*Most affordable*	Farmer Education programme to improve awareness of their role in AMR (7/10)
	Least affordable	Provide Rapid (potentially on farm) susceptibility and diagnostic testing for dairy cattle (3.7/10)
S	*Most positive side effects*	Farmer Education programme to improve awareness of their role in AMR (3.2/10)
	Least positive side effects	Removal of profit from veterinary antimicrobial sales (-1.2/5)
E	*Greatest equity*	Training to impart skills needed by farmers to reduce AMU while maintaining herd health and productivity (2.2/5)
	Least equity	Removal of profit from veterinary antimicrobial sales (-0.4/5)

6.3.2: Facilitated discussion of behaviour change interventions.

In groups, stakeholders discussed each proposed intervention, focusing on the pros and drawbacks of each intervention, potential ways to overcome barriers related to each intervention. The key points from these discussions can be seen in table 27 below, with the addition of any other interesting comments which were made in relation to the interventions.

Table 27: Key points made by stakeholders during the facilitated discussion of the behaviour change interventions to promote more responsible AMU on dairy farms.

Intervention	Pros	Drawbacks	Overcome Barriers	Other Notes
Farmer Education programme to improve awareness	• They are practical and effective. • Already been effective as requirement of the Red Tractor[1] scheme resulting in almost full attendance. • CAFRE[2] have had positive feedback on previous AMU training for farmers – There Is a lot of knowledge on it and a push for it. • Farmers are prepared to go if made easily available.	• Time pressures for farmers • If voluntary uptake may not be great but it will be effective to those that do. • Some courses can be information overload and not much is taken away by farmers.	• Better in person than online- get more out of it in terms of questions and answers at such an event. • It should be local and, in the evening, and easily accessible. • Option for online training course which are live interactive sessions rather than recordings. • Quizzes at the end to promote active listening.	• Quality of delivery is important. • Short and straight to the point messages to avoid information overload. • Red Tractor provides a lot of knowledge, we just have to listen.
Training to impart skills needed by farmers to reduce AMU while maintaining herd health and productivity	• A lot of farmers are up for preventative measures rather than relying on antibiotics. • How to use alternatives properly should be a big focus to improve success rate as well as when and why antimicrobials should be used. • Good to refresh farmer knowledge on how to use	• Very hard for farmers to have confidence to try alternatives to antibiotics - farmers will only be confident if they see results. • Many farmers combine alternative treatments with antibiotics. • Bound by time when deciding, and training won't make the	• The vet-farmer relationship can help with this type of training and confidence building. • Staff members on farms need the confidence and backing from their farmer – as they are less likely to take the risk of not using antimicrobials and being	• At a certain point it becomes trial and error for farmers, greater level of skill required when trying to reduce AMU as 9/10 times the desired effect is guaranteed with antibiotics. • Teat sealant is

	alternatives effectively while improving their confidence in such practices. • If done effectively will be a good approach to enable annual reduction of antimicrobial use . • Red Tractor provides an annual correlation of level of drugs used annually. • Such training provided as part of the Red Tractor scheme makes you aware of why antimicrobials should be used and if you are overusing while enabling farmers to benchmark against themselves and make improvements.	ultimate decision for farmers. • Older farmers less likely to engage in such training. • Makes good farmers better and others fall of - there is a wide spectrum of farmers out there	responsible if anything goes wrong. • Should emphasise that there is still a role for antimicrobials on farm, but responsible use is needed. • Getting the balance between anti-inflammatories and antibiotics in terms of cost and personal preference.	cheaper than SDCT approaches therefore there is no real incentive to participate. • In ROI- farmers have to show evidence that a cow needs an antibiotic, however ROI farmers do seasonal calving. • Milk recording could be good- better idea of what is going on.
Farmer peer information sharing groups for farmers to share experiences of reducing antibiotic use successfully with their peers and encourage others	• CAFRE Business development groups currently allow for farmers to do this. • Farmers have opportunity to discuss issues with each other. • It is a very positive activity.	• Can also work the other way i.e. a farmer tried something, and it didn't work – it only takes one bad experience to be shared and it tends to be louder than the one that worked. • Sometimes the information is a bit stale and repetitive. • Farmers want to get cow better ASAP and then onto next issue. • Farmers are primarily concerned with no antibiotic in tank and that is as far as it goes	• Discussion groups would have to be mediated to overcome this to remind farmers of the science behind such practices etc. • Make farmers aware of agenda- as depends on how group is organised/ facilitated. • Important that new information is provided and kept fresh. • Encourage farmers to bring information with them and to be prepared.	• A group of farmers at the mart could be considered a peer group and the discussion there can vary from what is actually scientific.

			• Apps would be good- Whatsapp chat etc.	
Positive reinforcement & feedback programs to build farmers confidence in their ability to reduce AMU safely on their farms	• Positive for farmers if they are engaged with program. • Vets can currently monitor SDCT and see its effects over time which can be passed on to farmers. • Red Tractor is already running something similar. • It is good as it makes you aware of what you use. • It is great to have advice, but it also has to be reflective on why a certain approach is not working. • Feedback from another farmer is huge.	• Difficulty finding data on AMU to give positive feedback • Very few farmers record clinical mastitis • Ab records are needed on a long term basis to properly see trends as other factors can play a part in herd health status • Farmers need to see differences to have confidence	• Need for recording systems that are easy to use and won't add an extra burden to farmers – e.g. parlour side systems. • Keep the groups the same- builds a level of trust as us farmers trust each other more	• There is room for a good story there – like the journey a farm went through to reduce AMU like a case study. How it worked, how many years did it take etc?
Vet training to enable them to educate farmers on AMR and help encourage farmer behaviour change	• Would be very well received. • Already a lot of vet CPD in the area. • Generally done in one-to-ones with farmers when they come to vets with an issue and usually their advice is well received. • Vets have to go through a justification process to use 4th generation AB and by going through that process you could have a cow fatality. • Perhaps this incentive would foster this important but currently fractured relationship?	• Feeling that vets do not communicate well with farmers. • Farmers feel like they haven't got any help from the vet on the issue of AMR YET- they need further explanation of why in some instances vets don't want to prescribe antimicrobials. • Farmers are annoyed that they can't get what they want because of the change in regulations- there is an element of under the table stuff where farmers can get	• Attitudes of farmers also need to change • Emphasis on the messaging/persuasion of farmers rather than the technical knowledge of AMR	• Many vets probably feel they already have a fair handle on it

		antibiotics from somewhere else.		
Mandatory vet training on AMR and how to reduce the need for use on dairy farms	• It would explain to farmers more about the reasons certain decisions are made. Rather than just no you can't have that and that's it. • Promote better relationship and farmer understanding. • Get all vets singing of the same hymn sheet.	• Vet /farmer relationship at the minute is strained • Larger animal vets are understaffed and do not have the time to spend with farmers. • Only one vet in a practice of 5 trained in AMR	• Making sure the information comes across to the farmer. • Vets should actually want to hep and implement and promote vaccination plans	• Not a vet in the country who isn't already very aware of this and such training is already happening
Legislation/guidelines for on vet per farm at any one period of time for antimicrobial prescriptions	• Would make a big impact on usage of antimicrobials - controlled use is effective use. • Farmers recently more prepared to get the vet out to see animals with increased prices of medications. • Being the sole prescribing practice would make doing farmers Red Tractor paperwork easier for vets and ensure messaging is consistent and a relationship is built, and more is learnt from that relationship. • In theory it is good, one farmer indicated that they keep the one vet for fertility and other checks.	• Antibiotics are prescription medicines but can be widely available from sources who don't value their worth and don't place importance on promoting responsible use. • Different vets have different ideas and treatment preferences. • Vets don't work 24/7	• DAERA[3] help needed from the top to help with this. • Encourage one vet practice rather than one vet.	• Multiple sources for antimicrobials is an enormous problem in fight against AMR • Red tractor hasn't improved farmer form filling/record keeping. • Health quality and monitoring by vets more difficult if there are multiple suppliers of medicines. • One veterinary practice may be more effective than one individual vet per farm
Removal of profit from veterinary antimicrobial sales	• Fantastic as vet bills are not getting cheaper from the perspective of farmers.	• Not very feasible, hard to implement and could result in the production of cheaper/less safe or effective medicines.	• Vet training on preventative measures instead • Vaccines have a significant	• Surprised that pressure from employers to sell antibiotics and

		• Danger of leading farmers to black market for medicines. • What will be reduced in revenue from the reduced profits from AMU- Vets will just charger more per hour.	mark up so vets can promote their use. • 20% of all vaccines makes you more inclined to buy more	unlikely to be the case within majority of vet practices. • Nice idea- but vets do need to make a profit to facilitate admin and keep the business going.
Provide Rapid (potentially on farm) susceptibility and diagnostic testing for dairy cattle	• Pilot testing of kits recently found farmers are open to receiving and trying them. • Good to know and understand the type of mastitis you have particularly as there are so many strains. • Allows you to treat that infection properly and avoid giving that animal the wrong drug. • There is a good understanding nowadays between sensitivity and susceptibility	• Time is still a factor with tests currently available being too slow. • Practically- it is unlikely that you would get the sick animal testes, results returned and treated intime before animal fatality. • Useful for helping farmers avoid further outbreak rather than used for the current case. • Useful but can't be relied upon as a sole measure to tackle AMU.	• Training in understanding and interpretation of tests by farmers necessary. • Tests can be precise and need to be done properly. • Ensure it is rapid enough to be used effectively and avoid fatalities. • Science has to bask it in some cases it might be enough to know if a bacteria is gram positive or negative to facilitate treatment or whether to tube cow or not	• Technology is coming along and can help farmers with their overall herd health. • More useful for well-run herds to fine tune health status. • Some veterinary practices have facilities in their practice to test scours and the likes which is really beneficial.
Vet peer information sharing groups where vets can share knowledge and experiences of working with farmers to successfully reduce AMU on farms	• Important for both farmers and vets • Helps vets confidence in decision making. • Useful platform to inform other farmers • Highlight to farmers the issues before the problems occur	• Smaller vet practices with 4-5 vets will only share good stories and not the bad • Farmers having difficulty in admitting that they have an issue. • Difficulty in sharing knowledge it is their business at the end of the day.	• Mobile phone WhatsApp group would be good for this. • Have a health protocol or standard operating procedure for symptoms and disease. • Provision of health manual for vaccines which is consistent and used	• Does happen within various veterinary groups and individual practices.

		often to have an effect.

[1]*Red Tractor: British food chain assurance scheme.*

[2]*CAFRE: The College of Agriculture, Food and Rural Enterprise (CAFRE) Northern Ireland.*

[3]*DAERA: The Department of Agriculture, Environment and Rural Affairs Northern Ireland*

6.4 Discussion

Farmer education programmes to increase awareness of their role in AMR was the highest ranked intervention proposed to reduce AMU on dairy farms within this study. This intervention option was ranked by participants as being the most practical, affordable, and eliciting the most positive effects when it comes to reducing AMU on dairy farms.

During the discussion stakeholders noted that educational programmes amongst dairy farmers had already proved effective as part of the Red Tractor scheme for example, and there has been positive feedback regarding previous AMU training aimed at farmers. It is believed that farmers are prepared to attend such training programmes if they are made easily available, are practical and effective. Time pressures for farmers is seen as the biggest barrier to attending training events and there is concern that if programmes are voluntary uptake may not be great but will be effective for those who do attend. It was also highlighted that some courses are "information overload" which can minimise their impact and what information farmers take home from the sessions. Therefore, training sessions should be concise and clear with the key points organisers want farmers to take away. Questions and answers during the sessions as well as quizzes at the end were suggested methods to improve the effectiveness of such programmes.

Previous literature has stated that good information provision, alongside clear communication are key factors influencing farmer behaviour. Long term, sustained engagement is needed to maintain changes as old behaviours often return after interaction cease (Alexander et al., 2015; Moe-Byrne et al., 2014). Previous research has reported that, regardless of the type of farming undertaken or the behaviour targeted by an intervention, interventions involving multiple exposure to knowledge transfer sessions have better results in terms of behaviour change (Grzywacz et al., 2013; Hruska & Corriols, 2002; Rattanaselanon et al., 2018). The results of this study, combined with previous literature this suggests that farmer education programmes to improve awareness of the role they can play in AMR and AMR stewardship is likely to facilitate reduced AMU on dairy farms.

Peer information sharing groups for farmers to share their experiences of reducing AMU successfully with their peers and encourage others to adopt such practices was also highly ranked by participants as having the potential to reduce AMU on dairy farms. Participants in this study perceived such information sharing groups as being the most acceptable and effective intervention for reducing AMU on dairy farms.

During the discussion it was highlighted that farmer business development groups currently allowed farmers to do this giving them the opportunity to discuss issues with each other. There was a consensus that this is considered a very positive activity. It was also highlighted that such

information sharing opportunities may not always be positive. For example, if one farmer tried something and it didn't work for them personally on that occasion, it could put other farmers off trying it. “It only takes one bad experience to be shared and it tends to be louder than the one that worked”. In order to overcome this, it was suggested that such discussion groups should be mediated, and farmers should be reminded of the science behind various practices.

The opinions of farmers’ peers are highly influential on their decision-making behaviour. The opinion of trusted peers could influence farmer behaviours through the provision of formal or informal advice (Rose et al., 2018). Peer support from like-minded individuals sharing similar issues is seen to be important when it comes to behaviour change of farmers (Rose et al., 2018). The notion of peer-to-peer knowledge exchange was also previously well received with farmers when it comes to influencing water pollution mitigation behaviours with farmers stating it is crucial to learn from other farmers with shared experiences (Inman et al., 2018). These findings therefore suggest that involving farmers in peer support groups to share their experiences of successful AMU reduction will help farmers take the necessary steps to use antimicrobials more responsibly on their own farms.

Training to impart skills needed by farmers to reduce AMU while maintaining herd health and productivity was another highly rated intervention amongst participants. This intervention was ranked highest for equity i.e., it was perceived to have the greatest potential to decrease differences between farmers when it comes to reducing AMU successfully.

During the discussion it was noted that a lot of farmers are interested in using preventative measures rather than relying on antibiotics and therefore how to use alternatives properly should be a key focus of such training, to improve the success rate of alternatives. It is believed that refreshing farmers’ knowledge on how to use alternatives effectively will improve their confidence to adopt such practices and change their current behaviours. If done effectively, it is perceived that such training will be useful and is considered a good approach to enable annual AMU reductions. It was highlighted that for farmers it can be hard to have the confidence to try alternatives to antibiotics as they are bound by time when faced with a sick animal and deciding what treatment they need. It was also acknowledged that the veterinarian-farmer relationship can help with this type of training and building farmer confidence. Finally, it was reported that the training should emphasise that there is still a role for antibiotics in farming, but that responsible use is vital.

When it comes to behaviour change, knowledge alone is not enough active demonstrations of behaviour can help raise an individuals’ confidence in their ability to perform a behaviour (Hendrie et al., 2017). Previous literature find that training was needed to equipped farmers with the practical skills and confidence to enable optic of positive environmental behaviours (Mills et al., 2017). hands

on learning to enable the development of specific skills and confidence is therefore suggested as an important behaviour change intervention to promote responsible AMU on dairy farms.

Positive reinforcement & feedback programs to build farmers confidence in their ability to reduce AMU safely on their farms was well received amongst dairy stakeholders as an acceptable, practical, effective and affordable strategy for promoting responsible AMU on farm.

During group discussions it was highlighted that something similar is currently incorporated within the red tractor scheme and such programs would be advantageous for farmers as long as they were engaged with the process. The need for recording on a long-term bases was noted as a potential downfall for this intervention as the availability of AMU data for farms is difficult to find. In order to overcome this, it was suggested that there is a need for efficient recording systems which are not going to be burdensome for already busy farmers e.g., parlour side recording systems.

Continuous feedback in performance based environmental management was found to be able to help farmer activate their conservationist farmer identities to establish new norms for practicing more sustainable agriculture (McGuire, Morton & Cast, 2013). This suggests that a program of positive reinforcement and feedback relating to farmers responsible AMU practices will help promote more responsible AMU on dairy farms. Consideration must also be given to encouraging farmers to engage in such programs and take ownership for their responsibility to strive for responsible AMU on farm.

Veterinarian training to enable them to educate farmers on AMR and help encourage farmer behaviour change was also highly rated amongst participants as a behaviour change intervention to reduce AMU on dairy farms. Such training was ranked relatively well by participants in terms of acceptability, practicability, effectiveness, affordability and having positive side effects when it comes to encouraging reduced am you on dairy farms.

During the group discussion it was suggested that such an intervention would be very well received, as veterinarians already undergo continuous professional development in the area of AMR. Generally, such education of farmers is done by veterinarians during one-to-one consultations when farmers come to them with an issue and usually their advice is well received. Participants felt that the attitude of farmers needs to change therefore placing an emphasis on the persuasion of farmers rather than the technical knowledge of AMR could potentially foster the important but currently fractured relationship between some farmers and veterinarians which helping to reduce AMU on farms.

Inspiring farmers to engage with behaviour change to improve herd health is a challenging role for veterinarians (Ruston et al., 2016). Motivational interviewing is one example receiving increasing attention when it comes to enabling that's to promote behaviour change amongst farmers (Bard et al., 2022). Motivational interviewing takes a collaborative conversation style approach to enhancing conversations about change (Bard et al., 2022). It has been suggested that motivational interviewing is perceived to be highly relevant to the veterinary profession and that training in such activity can create meaningful shifts towards consistent communication practise associated with increased client change talk (Svensson et al., 2020a; Svensson et al., 2020b). It was recently suggested that farmer motivation towards change maybe enhanced using a motivational interview consistent communication style (Bard et al., 2022). The findings of the current study suggests that training for veterinarians to persuade and encourage farmer behaviour change in relation to their AMU practices will be beneficial in achieving responsible AMU on dairy farms.

Veterinarian peer information sharing groups where veterinarians can share knowledge and experiences of working with farmers to successfully reduce AMU on farms was another strategy which was well received by stakeholders in accordance to the APEASE criteria.

It was reported during the discussions that this information sharing is important for both farmers and veterinarians and that it does happen within some veterinary groups and individual practices. Such an initiative is believed to help farmers confidence in the decision-making process surrounding veterinary prescription of antimicrobials.

It has previously been suggested that veterinary peer support groups could strengthen veterinarian relationships with farmers which could help less experienced veterinarians as it can be difficult to gain farmer confidence (Higgins et al., 2017). This suggests that behaviour change interventions should take into consideration the various social influences on veterinarian prescribing behaviour. Information-sharing opportunities for experienced veterinarians to share how they handled certain clinical situations, particularly those which may have involved a difficult client may help improve veterinarians' confidence in their knowledge and decision making and minimise the effect of client pressure.

Mandatory veterinarian training on AMR and how to reduce the need for use on dairy farms was seen by stakeholders as a positive strategy to help promote responsible AMU on dairy farms.

Discussions highlighted that such training would be beneficial as it could get all veterinarians "singing from the same hymn sheet" in that the advice provided by veterinarians to farmers in relation to antimicrobials would be standardised. It is believed that if such training helps get the

message across to farmers by explaining why certain decisions are made, rather than just being told they cannot have a particular medication prescribed, it could promote better farmer understanding and improve the currently strained relationship between some farmers and veterinarians. This suggests that training for veterinarians on practices which will reduce the need for AMU on dairy farms will be beneficial in promoting more responsible AMU on farm.

Providing rapid (potentially on farm) susceptibility and diagnostic testing for dairy cattle was deemed to be not overly affordable or practical as a strategy to promote more responsible AMU on dairy farms.

It was reported during group discussions that recent pilot testing of on farm diagnostic testing was well received with many farmers being open to trying such testing. It was agreed that such tests would be good to know what type of mastitis a cow has and to avoid giving incorrect medication. However, it is acknowledged that time would still be a factor and such tests would be useful more so to help farmers avoid further outbreaks rather than being useful for a current case. Stakeholders also referred to the importance of interpreting such tests as they would be precise and need to be carried out properly therefore training would be required to ensure farmers are able to carry out, interpret and understand the tests correctly. Based on these findings, at present on site testing is not recommended as a priority intervention for promoting more responsible AMU on dairy farms, however with improvements in technology and development of more timely testing, there is future potential for such testing to aid in reducing irresponsible AMU on dairy farms.

Legislation/guidelines for one veterinarian per farm at any one period of time for antimicrobial prescriptions despite potential benefits in theory, was not seen as a very practical strategy to promote more responsible AMU on dairy farms.

In order to overcome veterinarians concerns about losing clients, it was proposed that each farm being limited to a single veterinary practice would help build farmer-veterinarian relationships and help promote more responsible AMU on farms. Previous research also reported that Irish and Dutch veterinarians had suggested that each farmer should be assigned routine visits from one veterinarian, to promote good farm management practices and a consistent treatment approach, in addition to avoiding conflicts from other farmers and colleagues (Speksnijder et al., 2015, Magalhaes-Sant'Ana et al., 2017). This strategy was previously adopted in Norway, assigning one contracted vet per herd with mandatory veterinary inspections and clear reduction targets for livestock production which also improved overall herd health (Speksnijder et al., 2015). Stakeholders noted that farmers using multiple sources for antibiotics was a problem in the fight against AMR and one veterinary practice per farm would make health quality and monitoring by veterinarians much

easier while controlling AMU on farm. It was also proposed that another benefit of such legislation would be that messaging a farmer receives would be consistent and could help foster a better working relationship between farmers and their veterinary practice. However, it is believed that different veterinarians have different perspectives and treatment preferences therefore farmers like the idea of using a variety of veterinarians who can offer fresh ideas. These findings suggest that such legislation may be perceived as a burden by dairy farmers, however a focus should still be placed on building better working relationships between farmers and the veterinarians they deal with in order to build farmer confidence and enable a collaborative approach to achieving more responsible AMU on dairy farms.

Removal of profit from veterinary antimicrobial sales was the lowest ranked intervention to reduce AMU on dairy farms by participants. Removal of such profit was considered to be the least acceptable, practical, effective, beneficial, and lowest equity of the behaviour change interventions presented to participants.

During the discussion, it was a noted that such a change would not be very advantageous for any stakeholders. It was perceived that what would be reduced in profit from sales of antimicrobials would be made up for by veterinarians charging a higher rate for their time. There was also a concern amongst some stakeholders that such an intervention would be hard to implement but more so could result in the production of cheaper, less safe, or effective medicines and pose a danger of leading farmers to the black market for medicines. Veterinarian training on preventative measures was suggested as an alternative, more effective measure which should be promoted to reduce AMU. Likewise, it was suggested that veterinarians should promote vaccination programmes more, so that antimicrobials are not needed, and making vaccines cheaper than antimicrobials would make farmers more inclined to rely on vaccinations rather than antimicrobials.

The production of new antibiotics is greatly hindered by profitability challenges when it comes to antibiotics (Dutescu & Hillier, 2021). Antibiotics are already less profitable done other drug categories due to national programmes limiting seals and antimicrobial becoming ineffective due to AMR (Power, 2006; Outterson, 2014). The removal of veterinary profit from antimicrobial sales is therefore not suggested as an approach to promote responsible AMU on dairy farms.

6.5 Strengths and limitations

This study took the use of the COM-B model in determining behaviour change interventions to promote more responsible AMU on dairy farms to the next step by involving relevant stakeholders in the APEASE scoring process. This study provides a pilot which can be used for other researchers looking to gain insight from relevant stakeholders in relation to their target behaviour change.

As previously mentioned, due to time constraints the workshop could only be held with members of the Northern Irish dairy sector. Inviting representatives from the Republic of Ireland dairy sector was considered but given that there are slight differences in the regulations adhered to by both dairy farmers and veterinarians between the two regions it was decided that only Northern Ireland stakeholders would be invited to participate. Future work should identify the perceived effectiveness of the proposed behaviour change interventions from the perspective of the Republic of Ireland dairy stakeholders. Subsequently, a similar workshop including dairy stakeholders from the Island of Ireland as a whole may be useful to determine the similarities and differences between the two regions.

An additional limitation of this study was the low number of participants and the imbalanced representation of the veterinary profession as only one veterinarian was recruited. Veterinarians are extremely busy and finding a time to bring various members of the dairy sector together at the same time proved to be a challenge when conducting this study. Further research into perceived effectiveness of the proposed behaviour change interventions is necessary for all stakeholder within the dairy sector in order to gain a clearer picture of what interventions are deemed most feasible by the stakeholders they apply to.

6.6 Conclusion

Based on the findings of this facilitated discussion workshop, combined with evidence from previous literature this chapter has suggested a number of behaviour change interventions perceived as having the potential to promote responsible AMU on dairy farms. Farmer education programmes to improve awareness of their role in AMR, farmer peer information sharing groups to discuss experiences of reducing AMU successfully, training to increase the confidence of farmers to change AMU practices and training veterinarians to help encourage farmer behaviour change were considered by stakeholder participants as the most feasible intervention to elicit behaviour change and reduce AMU on dairy farms. Therefore, future intervention programmes should encompass a range of intervention functions in order to overcome the various barriers faced by farmers and veterinarians when aiming for more responsible AMU. The importance of stakeholder involvement in intervention program design has also been highlighted as they are the experts in their field and have more knowledge on how successful certain interventions will be.

6.7 Chapter 6 summary

This chapter presented the findings from a stakeholder workshop in which behaviour change interventions based on the findings of chapters 4 and 5 were presented to dairy stakeholders and assessed for their feasibility. This chapter highlights the most well received strategies, the reasons for stakeholder ratings and makes recommendations as to which strategies should be considered in future behaviour change intervention design for the promotion of responsible AMU on dairy farms.

7. Chapter 7: General discussion & conclusions

7.1 Introduction

Limiting AMU is seen as a vital step in limiting AMR development (WHO, 2020). It is widely acknowledged that research and policy efforts are needed to reduce agricultural AMU (FAO, 2016). Monitoring of AMU in livestock alone reveals little about what is driving AMU and so it is important to assess the behaviours of key stakeholders responsible for antimicrobial prescription and administration (Friedman et al., 2007). Understanding stakeholder attitudes, decision-making and the translation of behavioural intentions into sustained behaviour change, is an increasingly important discipline for policy design (Jones et al., 2015). Studies exploring the reasons for current AMU in agriculture are needed to design effective interventions to promote prudent agricultural AMU (Fischer et al., 2019).

The utilisation of theoretical frameworks for identification of barriers and enablers to prescribing can result in the development of antimicrobial stewardship interventions that may be successfully implemented and sustained (Craig et al., 2008; Ierano et al., 2019). The COM-B model has been used widely in human healthcare and consumer research (Barker et al., 2016; Cornish et al., 2019; Jackson et al., 2014; Kwah et al., 2019. The use of this behaviour change theory in agriculture is limited (Kropf et al., 2020; Irwin et al., 2021; Regan et al., 2021) and to has not yet been applied to investigate responsible prescribing and administration of antimicrobials on dairy farms by veterinarians and farmers respectively (to the best of my knowledge at the time of thesis completion).

This research therefore aimed to gain an understanding of the behavioural patterns of dairy farmers and veterinarians relating to AMU, to investigate their knowledge of and attitudes towards AMR and the highlight the current barriers and facilitators they perceive to experience when trying to use and prescribe antimicrobials responsibly. The final objective of this research was to identify and recommend behaviour change interventions using the COM-B model, to encourage more responsible AMU on dairy farms.

This chapter will summarise the thesis findings and highlight practical recommendations based on thesis results in the form of behaviour change interventions aimed at dairy farmers and veterinarians to promote responsible AMU to tackle the development of AMR. Additionally, it will discuss implications for the dairy industry, consider the limitations of this research and highlight the possibility for future research opportunities. Finally, the conclusions of this PhD thesis will be presented.

In the previous chapters each individual study results are discussed in detail and relevant conclusions drawn. In this discussion chapter, all the results of the studies will be considered together. The final conclusions consolidate the results of all the studies, considering the broader narrative and the contribution this work makes to the study of farmer and veterinarians' behaviour and antimicrobial use on dairy farms on the island of Ireland.

7.2 Current position of dairy farmers in relation to AMU & AMR and recommendations to promote responsible AMU

Farmers surveyed as part of this research exhibited a good level of AMR knowledge. Farmers understood that overuse of antibiotics can lead to them becoming ineffective, that the active ingredients in some antibiotics given to animals are the same as those used in human medicine, and that resistance in farm animals can be transferred to humans. Farmers were aware that AMR is a worldwide problem which could affect them and their families. Farmers reported that they were concerned about AMR for their family and animals, slightly more than they were for their own health. Similarly, farmers perceive the risk to the average person from AMR to be higher than the risk to themselves and their families, and that the risk to animals in other sectors to be higher than the risk to their own animals. Farmers felt that antibiotics are used too much in agriculture. However, many felt that they are used more in human medicine. Similarly, farmers believe antibiotics are used too much in their sector but also felt that such overuse is higher in other sectors. It is promising that the majority of farmers in this study accept that they, along with other stakeholders, have a responsibility to take action to reduce the risk of AMR for both humans and animals.

These results imply that despite having a relatively good knowledge of AMR and the risk it can pose, farmers risk perceptions are skewed based on who their concern is aimed at i.e., farmers feel that themselves and their animals are less at risk than other humans and animals. This display of optimism bias – a cognitive bias causing an individual to underestimate the possibility of negative events whereby they believe themselves to be less likely to experience a negative event (Sharot, 2011), has been found in previous research of farmers relating to AMU. Indonesian poultry farmers previously reported optimism bias, believing that AMR would not be an issue on their farms (Coyne et al., 2020). Excessive optimism can be hazardous as underestimating risk may reduce precautionary behaviours (Sharot, 2011).

To overcome this optimism bias farmers have illustrated, awareness of the levels of AMR should be raised in order to correct the misconceptions farmers have of the level of risk to themselves. Therefore, farmer education programmes relating to raising awareness in AMR is proposed as a

behaviour change intervention to overcome misconceptions relating to the risks associated with AMR and to promote acceptance of the role farmers can play in tackling AMR. Long term, sustained engagement is necessary to maintain behaviour change (Alexander et al., 2015; Moe-Byrne et al., 2014) and studies have shown that interventions involving multiple exposures to knowledge transfer have better behaviour change results (Grzywacz et al., 2013; Hruska & Corriols, 2002; Rattanaselanon, Robson & Siriwong, 2018). Further, when farmer education programmes to improve AMR awareness was ranked by stakeholders in a workshop this was considered to be the most practical, affordable method and eliciting the most positive comments in relation to reducing AMU on dairy farms.

This highlights that not only is there a need for such farmer education programmes, but that they are deemed by relevant industry stakeholders as being feasible within the dairy farming sector, making it a strong recommendation to help promote responsible AMU amongst dairy farmers.

When asked about making changes to their AMU, many farmers had either started to or had successfully made changes to their antibiotic use practices. However, a quarter of farmers had not yet or did not intend to make changes to their AMU practices. One of the reasons for not making changes despite being aware of AMR and accepting responsibility could be that the majority of these farmers believed that they knew how to use antibiotics and perceived their use on farm as being already responsible. Therefore, there is a need to document AMU at farm level and this information together with average use as well as responsible AMU values communicated to farmers, to motivate them to make the necessary changes on their farms.

Additionally, this research found discrepancies between farmers perception of how responsible their AMU on farm was and how responsible their individual practices associated with antibiotic use actually were. Despite believing they use antibiotics responsibly, irresponsible practices such as using antibiotics before consulting a veterinarian, keeping a stock of antibiotics on farm and giving antibiotics to prevent disease as part of their animal health management routine were reported. Similarly, despite many saying they always follow veterinarian instructions relating to antibiotics, some reported not always giving the full course and stopping use if the animal looks better.

These findings suggest that farmers unknowingly perceive their individual AMU practices to be more responsible than they actually are. Similarly, it was reported by previous literature that 65% of Ugandan poultry farmers surveyed believed they used antimicrobials in accordance with veterinary guidelines, however only 16% actually complied with guidelines (Kigozi & Higenyi, 2017). Additionally, it has also been reported that farmers and veterinarians had demonstrated a good

understanding of AMR stewardship, but their treatment decisions were not always aligned to stewardship principles (Golding, Odgen & Higgins, 2019).

In order to overcome the mismatch in farmers' perceived responsible use and their reported AMU practices, education and training on what constitutes responsible AMU practices are necessary. A recent systematic review found that elevating farmer knowledge through education influenced antibiotic use and encouraged appropriate practices on farms (McKernan et al., 2021). There is a need to educate farmers not only on responsible AMU but also on how to effectively implement responsible practices on farm. Such education could improve farmers' awareness of their current practices and those that need to change.

Farmers' perceptions of their own behaviours may also be skewed due to habit as many AMU behaviours being common practice for them. As experience of a behaviour is acquired, the influence of habit increases, and that of intention declines (Triandis, 1997). Farmers having used antibiotics previously to treat their animals, may see the positive outcome of their habitual actions and consider their behaviour to be responsible as it protects their animals at that moment. Despite being aware of the risks associated with AMU, when faced with the decision to treat animals using antibiotics, habit may be the reason for irresponsible practices. Therefore, awareness raising of specific behaviours and what constitutes "responsible" AMU behaviour should be targeted at dairy farmers rather than general knowledge transfer.

Alongside education programmes, training to impart skills needed by farmers to reduce AMU (while maintaining herd health and productivity) is recommended in order to enable farmers to firstly, understand what practices are considered responsible when it comes to AMU and secondly, to ensure that the farmers are confident in their ability to make changes to move towards more responsible practices. This recommendation could help bridge the gap between some farmers' perception of how responsibly they use antimicrobials and how irresponsible their individual practices actually are. Additionally, such training will improve farmers' confidence in their ability to make more responsible AMU decisions, while maintaining animal welfare, herd health and productivity all of which are current barriers in the farmer decision making process. When it comes to behaviour change knowledge alone is not enough, active demonstrations of behaviour can help raise an individuals' confidence in their ability to perform a behaviour (Hendrie et al., 2017). Workshops with dairy industry stakeholders showed acceptance of such training and participants believed that it would be the most beneficial in reducing differences between farmers within the dairy sector. Stakeholders believed that refreshing farmers' knowledge on how to use alternatives to antimicrobials effectively will improve their confidence to adopt such practices and change their

current behaviours. If done effectively, it is perceived that such training will be useful and is considered a good approach to enable annual AMU reductions.

Five variables were found to be significant predictors of farmers having stopped blanket use of antimicrobials (emotions related to reducing AMU, perception of being a good farmer, pressure to reduce AMU, objective knowledge and AMR awareness). The strongest predictors were AMR awareness and associating more positive emotions with reducing AMU. The more awareness of AMR and the more positive emotions expressed associated with stopping blanket use of antibiotics were, the more likely farmers were to have reported stopping blanket use of antimicrobials. Feeling more pressure to reduce AMU as well as lower overall objective knowledge were also predictors of respondents having stopped blanket use of antimicrobials.

Variables relating to capability (lower objective knowledge and greater AMR awareness), opportunity (feeling pressure to reduce AMU) and motivation (associating positive emotions with reducing AMU and positive perceptions of being a good farmer) were all significant predictors of whether or not dairy farmers had made changes to stop blanket use of antimicrobials. This suggests that interventions should consider farmer awareness of AMR, societal pressure to reduce AMU and improving farmers' perceptions of being a good farmer and emotions associated with stopping blanket antibiotic use to improve their chances of successfully changing farmer behaviour away from blanket use of antimicrobials.

In addition to the interventions previously recommended in this section it is also recommended that peer information sharing groups for farmers to share experiences of reducing antibiotic use successfully with their peers and encourage others to act and positive reinforcement and feedback programs to build farmers confidence in their ability to reduce AMU safely on their farms, should be explored by policy makers when aiming to promote uptake of more responsible AMU practices amongst dairy farmers. Stakeholders attending the workshops perceived peer information sharing groups as being the most acceptable and effective intervention for reducing AMU on dairy farms. The opinions of farmers' peers are highly influential on their decision-making behaviour. The opinion of trusted peers could influence farmer behaviours (Rose et al., 2018), with peer support from like-minded individuals sharing similar issues seen to be important when it comes to farmer behaviour (Rose et al., 2018). These findings suggest that involving farmers in peer support groups to share their experiences of successful AMU reduction will help farmers improve their confidence in taking the necessary steps to use antimicrobials more responsibly on their own farms.

Similarly, positive reinforcement and feedback programs to build farmers confidence in their ability to reduce AMU safely on their farms was recommended from this research. This intervention, as

well as building farmer confidence could also improve farmers' perceptions of themselves as good farmers. Continuous feedback in performance based environmental management was found to be able to help farmer activate their conservationist farmer identities to establish new norms for practicing more sustainable agriculture (McGuire, Morton & Cast, 2013). This suggests that persuasion techniques, such as positive reinforcement and feedback could build farmers confidence in their abilities and also importantly, help establish responsible antimicrobial practice as a new norm for being a good farmer.

These findings have positive implications for the promotion of behaviour change in relation to responsible use of antimicrobials by dairy farmers. The recommendations made based on findings of farmer surveys are supported by previous literature and also perceived as feasible and accepted by key dairy sector stakeholders as having the best potential for application in real world scenarios. The interventions recommended in this section, if implemented effectively by policy makers could help to empower dairy farmers to change their behaviours and result in more responsible AMU within the dairy farming sector.

7.3 Current position of veterinarians in relation to AMU & AMR and recommendations to promote responsible AMU

Veterinarians accepted a shared responsibility for taking action to reduce AMR. Rather than placing the blame on one individual group of stakeholders, veterinarians who were interviewed generally felt that anyone involved in the development, prescription, or use of antimicrobials both in animal and human medicine share the responsibility. Veterinarians were concerned about AMR for both humans and animals, this concern was slightly higher for humans and animals. Concern amongst veterinarians given their awareness of AMR, that there is a need to preserve antibiotics to prolong their effectiveness for treating both humans and animals. Veterinarians also expressed concerns that while they are willing to try to reduce antimicrobial use there are concerns that if antimicrobial use is too tightly restricted on farms, then ironically the welfare of animals in need of treatment may suffer. This suggests that veterinarians are willing to take action to promote more responsible AMU on dairy farms. Given that veterinarians themselves have concerns about AMR and its development, it is evident that they are motivated to take action to help tackle the issue. In order to enable veterinarians to act, it is necessary that help is provided for them to overcome the current barriers they perceive to be hindering their AMR stewardship efforts.

Application of the COM-B model found that lack of training to encourage farmer behaviour change (capability), issues with laboratory testing (opportunity), pressures from farmer clients to prescribe antimicrobials against their better judgement (opportunity), concern for the perceived negative

consequences of not prescribing antimicrobials such as animal welfare and farmers going elsewhere for prescriptions (motivation), are all factors veterinarians perceive to influence their AMR stewardship efforts. This suggests that for behaviour change interventions to be successful in promoting more responsible prescription of antimicrobials by veterinarians to farmers they should consider these factors (veterinarians' ability to encourage farmer behaviour change, improved laboratory testing, farmer pressure, concerns veterinarians have about not prescribing antimicrobials).

Veterinarians within this study displayed a good awareness and knowledge surrounding AMR, its associated risks and development. Veterinarians felt confident in their ability to perform antibiotic related tasks for example identifying the correct antibiotic for infections, calculating doses of antibiotics for an animal and complying with antibiotic protocols when treating animals. Generally, veterinarians reported that they intend to use antibiotics more responsibly. Veterinarians also intend to encourage farmers to implement alternative methods to using antibiotics such as using vaccine programmes and herd health planning. Veterinarians felt they could benefit from additional training on AMR and AMR stewardship. Veterinarians expressed a desire for specific training on how to promote behaviour change amongst their farmer clients. This suggests that although veterinarians have a good knowledge surrounding AMR, one of their barriers to promoting more responsible AMU amongst their dairy farmer clients is how to elicit behaviour change. Specific training on how to successfully promote behaviour change amongst farmers could aid veterinarians in their role as AMR stewards, given the important role they play in providing advice to farmers, by increasing their capability to promote responsible AMU.

Inspiring farmers to engage with behaviour change to improve herd health is a challenging role for veterinarians (Ruston et al., 2016). Motivational interviewing is one example receiving increasing attention when it comes to enabling veterinarians to promote behaviour change amongst farmers (Bard et al., 2022). Stakeholder workshop participants deemed veterinarian training to enable them to educate farmers on AMR and help encourage farmer behaviour change as a feasible behaviour change intervention. It was considered an acceptable, practical, effective and affordable intervention to help promote more responsible AMU on dairy farms. It was noted during stakeholder discussions that there should be an emphasis on the messaging to and persuasion of farmers rather than the technical knowledge of AMR. It was also suggested that such training would be well received by veterinarians and may also potentially improve the sometimes-fractured relationship between farmers and veterinarians, while achieving more responsible AMU behaviour change on farms.

Client expectation has also previously been reported as a barrier to antimicrobial stewardship amongst Australian veterinarians (Hardefeldt et al., 2018). Responding to client pressure was also a barrier noted by veterinarians within this study, particularly those who were less experienced in their fields. It was also reported that many veterinarians seek advice from their peers when it comes to deciding on prescription of antimicrobials. Information-sharing opportunities for experienced veterinarians to share how they handled certain clinical situations, particularly those which may have involved a difficult client may help improve veterinarians' confidence in their knowledge and decision making and minimise this effect of client pressure. It has previously been suggested that veterinary peer support groups could strengthen veterinarian relationships with farmers which could help less experienced veterinarians as it can be difficult to gain farmer confidence (Higgins et al., 2017). Veterinarian peer information sharing groups where veterinarians can share knowledge and experiences of working with farmers to successfully reduce AMU on farms, was well received during the stakeholder workshop as an approach to promoting more responsible AMU on dairy farms. It was perceived that such an intervention was acceptable, practical, effective and affordable and there was a consensus that it could improve veterinarians' confidence in their decision-making process when it comes to antimicrobial prescription. It is suggested that if effectively implemented such peer groups could improve veterinarians' opportunity to promoting responsible AMU on dairy farms.

Veterinarians were concerned that if they do not prescribe farmers with antimicrobials, they will go elsewhere to obtain the medication. In order to overcome veterinarians concerns about losing clients, it was proposed that each farm being limited to a single veterinary practice would help build farmer-veterinarian relationships and help promote more responsible AMU on farms. This strategy was previously adopted in Norway, assigning one contracted vet per herd with mandatory veterinary inspections and clear reduction targets for livestock production which also improved overall herd health (Speksnijder et al., 2015). Stakeholders noted that farmers using multiple sources for antibiotics was a problem in the fight against AMR and one veterinary practice per farm would make health quality and monitoring by veterinarians much easier while controlling AMU on farm. It was also proposed that another benefit of such legislation would be that messaging a farmer receives would be consistent and could help foster a better working relationship between farmers and their veterinary practice. However, this intervention wasn't as well received as other options, it was acknowledged that it would help veterinarians to understand the situation on each individual farm but it was also highlighted that different veterinarians may have different ideas and treatment preferences and that sometimes farmers like to obtain a fresh perspective from other veterinarians. These findings suggest that such legislation may be perceived as a burden by dairy farmers, focus

should still be placed on building better working relationships between farmers and the veterinarians they deal with in order to build farmer confidence and enable a collaborative approach to achieving more responsible AMU on dairy farms. Additionally, previously mentioned interventions such as training on behaviour change of farmers may help to build the relationship veterinarians have with their farmers which inadvertently may help overcome the issue of farmers going elsewhere for prescriptions and veterinary advice.

These findings have positive implications for the promotion of behaviour change in relation to responsible prescription of antimicrobials to dairy farms by veterinarians. The recommendations made based on findings of interviews with veterinarians are supported by previous literature and also perceived as feasible and accepted by key dairy sector stakeholders in terms of real-world implementation. If implemented effectively, the interventions recommended within this section could help to empower veterinarians and enable them to promote more responsible AMU on dairy farms.

Figure 7 below illustrates the interventions which are based on the COM-B model of behaviour change which should help overcome the factors perceived by farmers and veterinarians as barriers to using and prescribing antimicrobials prudently on dairy farms.

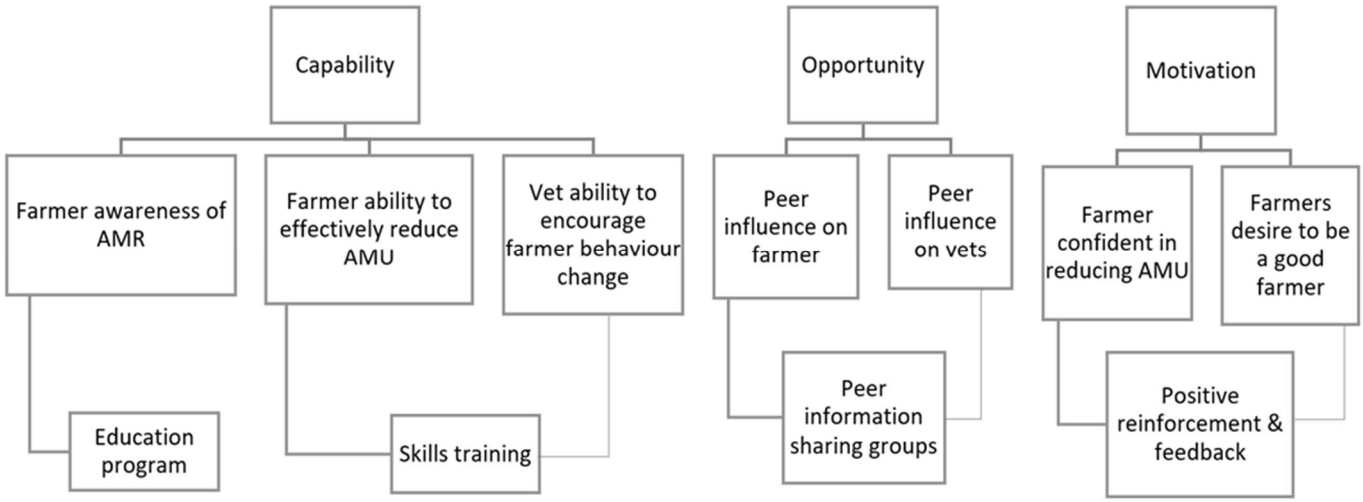


Figure 7: Relationship between influencers of responsible AMU, COM-B model components & behaviour change interventions

7.4 Potential impact and policy implications

AMR is a global health threat and therefore is notably an area of intense scientific focus. This research has made original contributions to this field of research which are important to achieve more responsible AMU on dairy farms. Knowledge gaps identified by the literature review (chapter 3) were used to design the quantitative and qualitative studies of farmers and veterinarians (chapters 5 and 6), which led to the proposal of behaviour change interventions which were evaluated by various dairy stakeholders for their feasibility and potential to promote more responsible AMU on dairy farms (chapter 7). This research has also generated further questions which can be pursued by future research. These implications are discussed below.

As previously highlighted, there is a need for evidence-based behaviour change interventions to effectively promote responsible AMU on dairy farms. Having applied the COM-B model of behaviour change to the findings of studies involving dairy farmers and veterinarians, two key stakeholders in AMU on dairy farms, this thesis proposes behaviour change interventions which should help achieve more responsible AMU on Irish dairy farms.

This work has identified that generally, dairy farmers and veterinarians on the island of Ireland accept a shared responsibility to tackling the issue of AMR and are willing to tack action to ensure their behaviours are responsible and therefore help slow and prevent the development of AMR.

Therefore, this work has positive implications for policy makers, dairy stakeholders and the general prescribing and use of antimicrobials in dairy cattle. This thesis provides behaviour change interventions, derived from stakeholder research, backed by behaviour change theory in the form of the COM-B model and perceived by various dairy sector stakeholders as feasible in the promotion of responsible AMU on dairy farms.

This work has the potential to help empower veterinarians and farmers to change their behaviour. The application of the proposed behaviour change interventions can improve their capability, opportunity and motivation to change their behaviour and prescribe and use antimicrobials more responsibly on Irish dairy farms.

Ultimately, this research could have positive implications on not only the health of dairy cattle but also wider animal populations and the general public. Successfully changing AMU on dairy farmers to a more responsible standard could help to minimise the risk of AMR development and its subsequent transfer to the human population. Most importantly, if prudent AMU is achieved within the agricultural medicine, the effectiveness of antimicrobials may be preserved and prolong the success of antimicrobial treatments for both animals and humans.

7.5 Strengths, limitations and future research

Individual chapters of this thesis have discussed the strengths, limitations and recommendations from each study (chapters 5-7). This section will summarise the key strengths and limitations of this thesis as a whole and make recommendations for future work.

7.5.1 Strengths of this research

This PhD utilised mixed method methodologies, the combination of quantitative and qualitative approaches helped to establish deeper understanding of antimicrobial use and prescribing on dairy farms. This research involved multiple stakeholders within the dairy sector, identifying the barriers and facilitators to responsible behaviour of both farmers and veterinarians provides a more holistic overview of what influences responsible AMU on dairy farms (from prescription to administration). This thesis enabled the triangulation of data from the various studies to gain a better overall understanding of the current position of dairy farmers and veterinarians relating to AMU and AMR.

The stakeholder workshop provided an ideal platform to disseminate the research findings to key representatives of the NI dairy sector and this is believed to be another important strength of this research. This research went a step further than previous literature in the field, not only due to the application of a theoretical behaviour change model to its findings, but more importantly by bringing together key stakeholders to get their input on the real-world potential impact of the proposed behaviour change interventions.

The use of the COM-B model within this thesis has strengthened the understanding of the decision-making process undertaken by farmers and veterinarians when choosing to treat dairy cattle with antibiotics. This is the first time the COM-B model has been applied to the responsible use of antimicrobials on dairy farms for research involving both farmers and veterinarians. This thesis highlights the applicability of the COM-B model to this area of research. The use of the COM-B model in this area has laid the foundations for behaviour change interventions which can be linked to psychological theory to promote more responsible use and prescription of antimicrobials in dairy farming by farmers and veterinarians respectively.

The contributions from stakeholders in the development of behaviour change interventions are key to ensure that views from those who will use the intervention in the real world have been included to maximise the likelihood of success at implementation (Faija et al., 2021). This research has not only identified the barriers to responsible AMU on dairy farms, further, it has proposed behaviour change interventions based on behaviour change theory and then utilised the opinions of key stakeholders within the sector to identify those which are likely to be most impactful.

7.5.2 Limitations and future work

Despite the novel contribution of this thesis, there are several limitations and possibilities for future work which must be considered.

AMR is currently a very topical global health issue and the surveys and interviews evaluated self-reported behaviours and attitudes; therefore, findings could be subject to some level of social desirability as it relied on participants to be honest in their opinions and accurately recall their behaviours. This research required respondents to self-rate their levels of knowledge and awareness relating to AMU and AMR, there is the possibility that respondents may over report socially desirable behaviours or under report behaviours that are socially undesirable. Therefore, limitations such as social desirability bias and recall bias must be taken into consideration.

Studies in chapters 5 and 6 relied on convenience sampling, despite being an accepted and valid method of sampling, its use may introduce the potential for selection bias and so results should be interpreted with caution. Participation in this research was voluntary and so there is the likelihood that those who took part already have a greater interest in the issue of AMR than some of their peers may have. Future research could focus on collecting data particularly from veterinarians using questionnaires over a larger sample size to help validate the findings of veterinarian interviews.

The overall sample size of the veterinarian study could be considered relatively small compared with other research, particularly the low number of responses for the veterinarian online survey. One obstacle when conducting this recruitment was the limitations resulting from data protection regulations. Recruitment relied on help from external veterinary organisation. It should also be acknowledged that farmer surveys were sent during the Covid-19 global pandemic, which was an extremely stressful period for everyone including farmers which may have resulted in a lower response rate. Likewise, veterinarian interviews were conducted during the pandemic which prevented interviews being carried out face-to-face as originally planned. If it has been possible to visit veterinary practices in person there may have been a greater uptake amongst veterinarians compared to the reliance on telephone or video calls, particularly at a time when “zoom fatigue” was being experienced by many employees in various sectors (Wolf, 2020). Despite this, data saturation was achieved through the twelve interviews conducted with veterinarians indicating that the key relevant points were obtained for this study.

Veterinarians were also not well represented in the stakeholder intervention assessment workshop, with only one dairy veterinarian present, therefore findings are not representative of the dairy veterinarian population. Future work around the feasibility assessment of behaviour change interventions could include a short survey of veterinarians to determine their perceptions of the

various behaviour change interventions to promote more responsible AMU on dairy farms. As mentioned in the previous chapter, due to time constraints the stakeholder workshop only included representatives of the Northern Irish dairy sector and only included 10 stakeholders in total, similar to the previous recommendation, an online survey of various dairy sector stakeholders in both Northern Ireland and Republic of Ireland could provide a clearer illustration of the perception dairy stakeholders have of the proposed behaviour change interventions to promote more responsible AMU on dairy farms on the island of Ireland

Additionally, the current studies recruited dairy farmers from the Island of Ireland and so findings may not be fully generalizable to different farming sectors and countries without further research. It should also be noted that these results are based on perceptions and are therefore subjective. It cannot be presumed that findings are representative of all individuals within the examined stakeholder groups.

Participants referred to various schemes and systems already in place such as Red Tractor, Farm Vet Champions, Royal College of Veterinary Surgeons, and Farm Quality Assurance. Future work could explore such scheme and promote harmonisation of their prioritisation and approaches to promoting responsible AMU on dairy farms. Additionally, further research may be warranted of the wider dairy supply chain including dairy processors, government and industry bodies such as Department of Agriculture, Environment and Rural Affairs (DAERA), Ulster Farmers Union (UFU) and VetNI to determine what role such actors may play in aiding collaborative efforts to achieve more responsible AMU on dairy farms.

It was difficult to decide which behaviour change theory or model to use for this research. Alternative frameworks which could have been applicable include the social ecological framework which can be used to explore the dynamic interplay between psychological (e.g., beliefs, risk perceptions) and contextual (e.g., economics, industry norms) factors (Green, Richard & Potvin, 1996; Stokols, 1996). Social ecological frameworks have been utilized previously in veterinary contexts to identify barriers to improved biosecurity on dairy farms (Shortall et al., 2016) and to explore farm veterinarians' and farmers' beliefs about AMU and AMR and how these beliefs may impact antimicrobial stewardship (Golding et al., 2019). Additionally, The Integrated Behaviour Model (IBM) is a model for understanding and influencing behaviour with a focus on intentions and motivation which may have been useful in this setting. The model integrates two influential psychological theories: Self Determination Theory and the Theory of Planned Behaviour, addressing the gaps that the two theories have separately (Hagger & Chatzisarantis, 2014). The IBM is very comprehensive, incorporating both reflective and automatic processes that influence behaviour

however The IBM (similar to the Self Determination Theory or the Theory of Planned Behaviour) has mostly been used in the context of health behaviour, and its effective application to other contexts is less clear (Caudwell et al., 2019).

The COM-B model is an established method for understanding behaviour and used extensively in behaviour change interventions (Timlin et al., 2021). Given that the objective of this thesis was to propose behaviour change interventions to promote more responsible AMU on dairy farms, the COM-B model of behaviour change was deemed the most suitable model of behaviour change. The COM-B model can be used to design behaviour change interventions in a systematic manner which could be easily followed by the researcher (Michie, Atkins & West, 2014).

The next step in the process of developing behaviour change interventions is to determine which specific behaviour change techniques (BCT) would be most suitable for the intervention functions proposed, a step which was not included as part of this work. If more time had been available this is something which would have added to the value of this thesis. A variety of BCTs exist, which are usefully categorised into 16 themes (Michie et al., 2013). Utilisation of BCT is common in the health and social care sector, having been used previously to foster behaviour change in the areas of; physical activity and lifestyle, and hospital antimicrobial practices (Flannery et al., 2019; O'Dwyer et al., 2019; Davey et al., 2015). There has been limited utilisation outside the healthcare field and specifically within the agricultural sector. There is currently PhD research being undertaken within Queen's University Belfast, to determine how training veterinarians and farm advisors in BCTs can impact on their ability to support farmer AMU behaviour change, which will compliment this thesis well in due course.

Overall, on reflection, if this work was to be repeated the key changes recommended would be to increase the participation rate particularly of veterinarians, hold larger workshops to assess the proposed behaviour change interventions with a more balanced mix of dairy stakeholders on the island of Ireland and to add some degree of analysis relating to specific behaviour change techniques which could be used by veterinarians. Despite this the work conducted to produce this thesis has some novel aspects as previously mentioned and made some good contributions to this field of research.

7.6 Conclusions

AMR poses a significant threat to the health of humans and animals, currently considered a major global health concern. Given the prevalence of AMR, the association between irresponsible use of antimicrobials in agriculture and the development of resistance and the reliance on AMU in dairy cattle, this thesis has provided a comprehensive view of the current position dairy farmers and

veterinarians find themselves in when trying to achieve responsible AMU. The use of multiple data collection methods has enabled this thesis to identify the perceptions of dairy farmers and veterinarians to AMU and AMR, two key stakeholders in the use of antimicrobials in dairy farming, and the barriers currently impacting on their AMR stewardship efforts.

Having greater awareness of AMR and AMU, feeling social pressure to reduce AMU, associating positive emotions with stopping blanket use of antimicrobials and farmer perceptions of what being a good farmer in relation to what makes a good farmer, were all significant predictors of farmers stopping blanket use of antimicrobials. Lack of training to encourage farmer behaviour change, issues with laboratory testing, pressures from farmer clients to prescribe antimicrobials, concern for the perceived negative consequences of not prescribing antimicrobials were the barriers identified as restricting veterinarians AMR stewardship efforts. While having a good knowledge of AMR, peers as a source of prescribing advice and accepting a shared responsibility for AMR, were perceived as facilitators to veterinarians in their role as AMR stewards.

Application of the COM-B model guided the proposal of behaviour change interventions to promote more responsible AMU on dairy farms based on the barriers and facilitators reported within this research. Gaining the opinions and feedback from multiple stakeholders deemed the feasibility of the proposed behaviour change interventions and resulted in the recommendation of six main interventions to promote responsible AMU on dairy farms. This thesis proposed that future interventions should seek to; improve the knowledge and skills of farmers in relation to AMR and how to reduce AMU safely, equip veterinarians with the necessary skills and confidence to encourage behaviour change amongst farmers, provide positive reinforcement and feedback to farmers as they make changes towards responsible AMU and focus on peer information sharing groups for both farmers and veterinarians to enable encouragement from peers to adopt responsible AMU practices responsibly.

Findings of this thesis can provide guidance for policy makers when deciding on strategies to promote responsible AMU on dairy farms. As the concern for AMR continues to increase, this thesis provides evidence-based, practical recommendation, backed by various dairy stakeholders to help overcome irresponsible AMU on dairy farms and tackle the growing threat of AMR.

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Appendix 1: Systematic review search strategy

Database searched	Search terms used (Searches bases on title and abstract)	Results retrieved	Articles retained based on title and abstract
Medline	"dairy" and "Farmer" and "antimicrobial resistance"	9	5
	“dairy" and "farmer" and "antibiotic use	9	4
	"Dairy" and "veterinarian" and "antimicrobial resistance"	5	1
	"Dairy" and "veterinarian" and "antibiotic use"	2	1
Embase	"dairy" and "Farmer" and "antimicrobial resistance"	10	4
	“dairy" and "farmer" and "antibiotic use	8	4
	"Dairy" and "veterinarian" and "antimicrobial resistance"	12	4
	"Dairy" and "veterinarian" and "antibiotic use"	14	7
Scopus	"dairy" and "Farmer" and "antimicrobial resistance"	46	10
	“dairy" and "farmer" and "antibiotic use	35	8
	"Dairy" and "veterinarian" and "antimicrobial resistance"	44	3
	"Dairy" and "veterinarian" and "antibiotic use"	25	4
Pubmed	"dairy" and "Farmer" and "antimicrobial resistance"	9	5
	“dairy" and "farmer" and "antibiotic use	9	4
	"Dairy" and "veterinarian" and "antimicrobial resistance"	7	2
	"Dairy" and "veterinarian" and "antibiotic use"	9	5
Web of Science	"dairy" and "Farmer" and "antimicrobial resistance"	13	7
	“dairy" and "farmer" and "antibiotic use	15	3
	"Dairy" and "veterinarian" and "antimicrobial resistance"	12	2
	"Dairy" and "veterinarian" and "antibiotic use"	16	4
	Total	309	87

Appendix 2: Study 1

Appendix 2a: Participant information sheet

PARTICIPANT INFORMATION SHEET – Dairy survey

Research Project Title

Knowledge, attitudes and behaviour of farmers and vets in relation to antimicrobial use on dairy farms.

You are being invited to take part in this research project. Before you decide to do so, it is important that you understand why this research is being conducted and what it will involve. Please take some time to read the following information carefully. Please email me at sfarrell11@qub.ac.uk if you have any questions or if you would like more information. Thank you for your time.

The purpose of this research

This research project aims to investigate dairy farmers understanding of antibiotics. It will also explore perceptions, attitudes and opinions that influence behaviours towards antibiotic usage. The project will build upon other research carried out and has been designed to allow comparisons with previous findings, to better understand the behaviours in relation antibiotic usage on the Island of Ireland.

Why have you been invited to take part?

You have been chosen as you are involved in the production of food. It is important to explore your perception, attitudes, knowledge, and opinions in relation to antibiotics, to obtain a better understanding on what influences your behaviour surrounding antibiotic usage.

Do I have to take part?

It is up to you whether or not you take part. You can change your mind and withdraw at any stage by closing your browser window. Please note that by taking part in this survey after reading the participation information sheet and providing consent you are allowing your data to be included in this research. **At the beginning of the study you will be asked to provide your own unique 4-digit ID code**. Your data will only be identified by unique 4-digit code you provide which only the researcher has access to, **and the IP address tracking will be turned off**. Meaning your information is pseudonymous for the purposes of withdrawal, only the researcher will be able to link you to your data. It is **important that you keep/ remember the unique code you provided** as if you want to withdraw your response from the database you will have to contact researcher Sarah Farrell (sfarrell11@qub.ac.uk) and provide your unique code, within 2 weeks from survey completion, as data will be aggregated. You do not need to give a reason for withdrawing and this will have no effect on any future relationships with Queen's University Belfast. The data you provide will be stored in a password protected file on university premises, all data will be kept for no longer than is necessary and will be destroyed after this time.

What will happen if I take part?

You will be asked to take part in a short online survey consisting of a series of questions lasting approximately 20 minutes.

Who is funding the research?

The project is funded by DAERA postgraduate studentships and Safefood Ireland.

What do I have to do?

Please answer all the questions as openly and honestly as possible. Questions are based on attitudes and perceptions, there are no right and wrong answers. At the end of the survey you will be required to provide some general demographic information. If you feel uncomfortable answering these questions you have the option to select 'prefer not to say'. There are no other commitments associated with participation.

What are the possible disadvantages and risks of taking part?

We do not anticipate that you will experience any negative effects from taking part in this survey.

What are the possible benefits of taking part?

Once the survey is completed, on a "first come-first serve basis" participants will be eligible for a £15 'one for all' e-voucher, as gratitude for your time taken to complete the survey. To obtain this voucher an email address should be provided. However, if you do not have an email address, a postal address can be provided to receive your voucher. Additionally, this work will have a beneficial impact within this field by contributing to findings that may be used to better farming practices.

What if something goes wrong?

If you have any concerns about any aspects of the study, you can contact the Chief Investigator, Professor Moira Dean. Should you remain unhappy and wish to make a formal complaint, you can contact the Research Governance Team at Queen's University Belfast (Telephone: 028 9097 2529; Email: researchgovernance@qub.ac.uk).

Will my information be confidential if I take part in this project?

All the information collected about you during the course of the research will be kept strictly confidential, and your data will only be identified by the unique code that you provide which only the researcher has. Any data collected about you during the survey will be stored in accordance with the General Data Protection Regulation 2016/679. Data collected may be shared in an anonymous form to allow reuse by the research team and project partner, Teagasc. These anonymised data will not allow any participants to be identified or identifiable.

What will happen to the results of the research project?

Results of the research will be published. You will not be identifiable in any report or publication.

Contacts for further information

Sarah Farrell, School of Biological Sciences, Queen's University Belfast, Northern Ireland. Email: sfarrell11@qub.ac.uk
Professor Moira Dean, School of Biological Sciences, Queen's University Belfast, Northern Ireland. Email: moira.dean@qub.ac.uk
The School of Biological Sciences Office, 19 Chlorine Gardens, Belfast, BT9 5DL, Northern Ireland. Tel: +44 (0)28 9097 5787, email: biolsci@qub.ac.uk

This research will be conducted in compliance with data protection legislation. For more information about how we look after your information, how to access your rights and who to contact if you have any queries or concerns about data protection please visit the Queen's University Belfast website - www.qub.ac.uk/privacynotice/Research/ListofResearchPrivacyNotices/PrivacyNoticeforResearchParticipants

Appendix 2b: Farmer survey

Understanding Irish Farmers' Views about Antibiotics: Cross-sector Survey

CONSENT FORM: (Please read through statements verbally with participant)

CONSENT FORM

Participant ID:

Title of Project:	Use of antimicrobials in animal health on the Island of Ireland: knowledge, attitudes, and behaviour
Chief Investigator:	Dr. Claire McKernan
Study Number:	

Please initial box

1. I confirm that I have read, or had read to me, and understand the information sheet dated 29/10/2020, version V2 for the above study. I have had the opportunity to ask questions and these have been answered fully. ☐
2. I understand that my participation is voluntary, and I am free to withdraw at any time, without giving any reason and without my legal rights being affected. If you want to withdraw your response from the data base, you have 2 weeks to do so, as after this date the data will be aggregated. ☐
   I understand that I have to keep the **individual code I provided** at the beginning of the survey if I want to withdraw my response.
3. I understand the study is being conducted by researchers from Queen's University Belfast and that my personal information will be held securely on University premises and handled in accordance with the provisions of the Data Protection Act 2018. ☐
4. I understand that data collected as part of this study may be looked at by authorized individuals from Queen's University Belfast and regulatory authorities where it is relevant to my taking part in this research. I give permission for these individuals to have access to this information. ☐
5. I agree to take part in the above study. ☐
6. I understand that the information I provide may be published as a report. Confidentiality and anonymity will be maintained, and it will not be possible to identify me from any publications. ☐
7. I understand the interviews or observations will be tape recorded, and there is a possibility of direct quotation being used in publications. ☐

_____	_____	_____
Name of Participant (please print)	Signature	Date
_____	_____	_____
Name of Person Taking Consent (please print)	Signature	Date

Chief Investigator or Researcher Contact details: Dr Claire McKernan c.mckernan@qub.ac.uk

Q1. Please enter a 4-digit code.
To generate your code, please follow the instructions:
First letter**:** First letter of the town you were born
Second- & third digits: Last 2 numbers of your phone number
Fourth Letter: First letter of your primary school

Q2. What is your age?

Q3. Please indicate in which **county** in Ireland/Northern Ireland your farm is located.

Q4. Please indicate which agricultural sector you work in.

Beef	
Dairy	
Pig	
Sheep	
Combination / Mixed	
None of the above	

Q5. Please indicate the herd size of your farm.
If you have a mixed enterprise, please fill in the options that are relevant to you.

Beef (breeding)	The number of *breeding cows* on my farm is:	
Beef (dry stock)	The maximum number of *stock* on the farm at any point during the year is:	
Dairy	The number of *dairy cows* on my farm is:	
Pig (Breeding /Integrated)	The number of *sows* on my farm is:	
Pig (Finishing only)	The number of *finishers* on my farm is:	
Sheep	The number of *ewes* on my farm is:	

Q6. If you have a **mixed enterprise**, please indicate the dominant sector within your business. **Please keep this sector in mind when answering the remaining questions.**
If you already selected 'beef', dairy', 'pig' or 'sheep', go to Q7

Beef	
Dairy	
Pig	
Sheep	

The following questions aim to gather information on how antibiotics are used in Ireland. Please think about how you normally use antibiotics on your farm when answering the questions.

Remember that all answers are <u>completely anonymous</u> and will only be used to gain an overall picture, rather than to measure antibiotic use on individual farms.

If you are unsure about answering something, please select 'I don't know'.

Q7. Please indicate how often you do the following practices on your farm

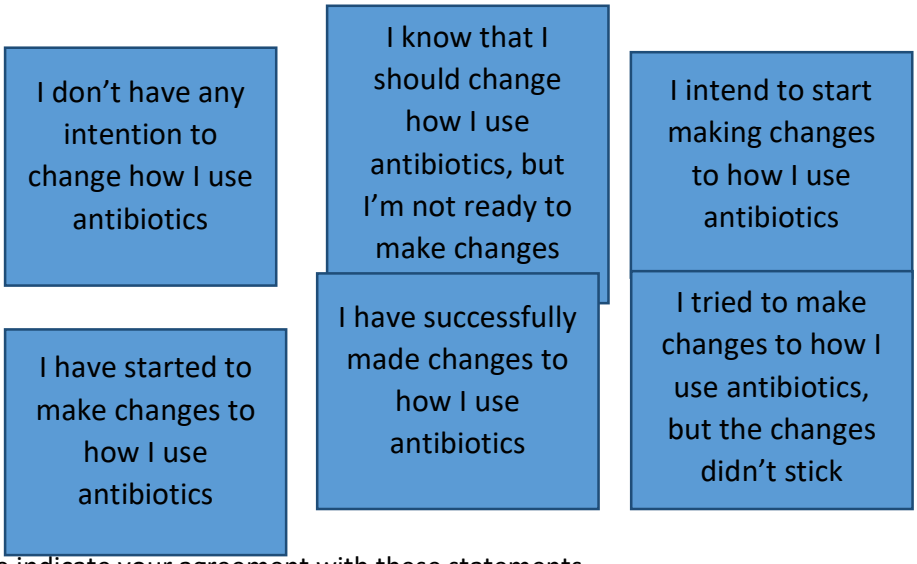
	Never	Rarely	Sometimes	Frequently	Always	I don't know	Prefer not to say
I follow the dosage instructions given by the vet when using an antibiotic							
I follow the instructions given by the vet on how to administer an antibiotic							
I follow the instructions for storing antibiotics safely (e.g., refrigeration)							
I store antibiotics in a secure location such as a locked fridge or medicine cabinet							
I follow the instructions for disposing of antibiotics safely once they are expired or empty							
I record the antibiotic usage on my farm							
If the animal looks better, I stop the antibiotic before the end of the prescription							
I give the full course of antibiotics as written in the prescription							
I keep a stock of antibiotics on my farm to treat common diseases							
Giving antibiotics to animals to prevent disease (e.g., blanket use) is part of my animal health management routine							
If an animal gets sick, I give antibiotics to the whole group to prevent the spread of disease							
I share antibiotics with other farmers if they are stuck.							
I get the antibiotics I use on my farm directly from a vet							
When animals get sick, I use antibiotics before consulting a vet.							

Q8. When do you record your antibiotic usage?

Immediately after I use the antibiotic	
Weekly	

Monthly	
Quarterly	
Annually	
Before an inspection	
Never	

Q9. Please choose a box that best represents your farm practices in relation to antibiotics used on your farm:



Q10. Please indicate your agreement with these statements.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I believe antibiotics are used too much in agriculture					
I believe antibiotics are used too much in human medicine					
I believe antibiotics are used too much in my sector					
I believe antibiotics are used too much in other sectors					

Q11. Please indicate your agreement with the following statements.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I am aware of how to use antibiotics					

I feel like I have enough knowledge about antibiotics					
Compared to the average farmer, I know a lot about how to use antibiotics					
I believe I use antibiotics responsibly on my farm					

Q12. To the best of your knowledge, do you think these statements are true or false?

			How sure are you that the answer you gave is correct?				
	True	**False**	**Very unsure**	**Quite unsure**	**Slightly unsure**	**Quite sure**	**Very sure**
Antibiotics can kill bacteria							
Overuse of antibiotics makes them become ineffective to treat animals							
The active ingredient in antibiotics given to farm animals are the same as those given to humans							
Overuse of antibiotics makes them become ineffective to treat humans							
Bacteria which are resistant to antibiotics in farm animals can be transferred to humans							
Antibiotics can kill viruses							
Certain antibiotics are reserved for human use							

Q13. Please select 'yes', 'no', or 'I don't know' for the following statements.

	Yes	No	
I am aware of the issue of antibiotic resistance			
	Yes	No	I don't know
Antibiotic resistance is a problem in my country and worldwide			
Antibiotic resistance is an issue that could affect me or my family			

Q14. Please select 'yes' or 'no', for the following statements.

	Yes	No

I am aware of the topic of 'One Health'		
I am aware of the links between animal health practices and human health		
I am aware of the link between antibiotic use on farm and antibiotic resistance in humans		

Please read this explanation of the term 'antibiotic resistance':
Antibiotics are used to kill bacteria. They are an important medicine for treating infections in humans and animals. However, the more antibiotics are used, the less effective they become at killing the harmful bacteria. This is known as *antibiotic resistance*. You might also have heard of it as *antimicrobial resistance* ('AMR'). Antibiotic resistance means illnesses in both human and animals are much harder to treat.

Q15. How concerned are you about antibiotic resistance for…

	Not at all concerned	Slightly Concerned	Moderately concerned	Very Concerned	Extremely concerned
… your animals' health					
…human health					
… you and your family's health					

Q16: Please indicate your feelings of risk for the following statements.

	Very low	Low	Moderate	High	Very high
The risks to the **average person** of antibiotic resistance are…					
The risks to the **average farm animal** of antibiotic resistance are…					
The risks to **my animals** of antibiotic resistance are …					
The risks to **my family and me** of antibiotic resistance are….					

Q17. Please indicate your agreement to the following statements.

A good farmer is one who...

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
… is progressive in using new farming approaches and strategies					

…makes decisions based on evidence and data					
…keeps up to date with the latest scientific advice and recommended practices					

Q18. How much responsibility do you believe lies with each of the following groups to **take action** to reduce the risk of antibiotic resistance for humans and animals?

	Not at all responsible	Slightly responsible	Moderately responsible	Very responsible	Extremely responsible
Food Consumers					
Food processors / manufacturers					
Restaurants / fast food chains / caterers					
Farmers in my sector					
Farmers in other sectors					
Retailers					
Government departments (including DAFM, DAERA)					
Medical doctors					
Veterinarians					
Scientists					
Pharmaceutical companies					
Public organisations (e.g., NHS, HSE, WHO)					

Please read the following...

John is a farmer who has recently made changes to how he uses antibiotics. He made a plan to manage his herd's health and prevent disease occurring. He now no longer uses antibiotics with his whole herd to prevent disease breaking out (blanket use), and where possible only gives antibiotics to the animals who show clinical signs of disease.

Q19. I have made similar changes to John on my farm

Yes	

No	
I don't know	

Q20. If you had to stop blanket use of antibiotics, and make the same changes as John on your farm, how do you think it would make you feel?

	1	2	3	4	5	
Dissatisfied						Satisfied
Foolish						Wise
Worried						Calm

Q21. Please indicate your agreement with the following statements.

If I had to stop the blanket use of antibiotics…

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I am confident that I can make changes similar to John on my farm.					
I am confident that I would know what to do					
I believe I have the ability to make changes similar to John					

Q22. If you had to stop blanket use of antibiotics, how helpful do you think any of the following would be to help you to make similar changes to John on your farm?

	Not at all Helpful	Slightly Helpful	Moderately Helpful	Very Helpful	Extremely helpful
New government financial grants to support antibiotic reduction on farms					
Subsidised vaccination programmes					
Publish national averages for antibiotic use across sectors.					
New policies and regulations to restrict antibiotic use on farms					
Consumers paying more for produce coming from farms which have proven responsible antibiotic use					
A quality assurance scheme which would include using a new label/logo to alert consumers to produce coming from farms which have proven responsible antibiotic use					

A farmer receiving a financial bonus from the processor for taking action to reduce their antibiotic use on the farm					

Q23. What services do you avail of from your vet? (tick as many as applicable)

To prescribe medication to treat animals	
To carry out procedures (e.g., birthing, castration)	
Mandatory testing (e.g., TB testing)	
To carry out a welfare assessment (e.g., tail biting risk)	
To carry out a biosecurity assessment	
Laboratory testing to diagnose disease	
To get advice on herd health management	
To get advice on reducing antibiotic use	
To plan vaccine programmes	
To make herd health plans	
To get nutrition advice	
None of the above	
Other (please specify)	

Q24. When an animal is sick, how often do you consult the following for advice...

	Never	Rarely	Sometimes	Frequently	Always
Myself / my own judgement					
Someone else on my farm					
Another farmer					
A farmer discussion group					
A farm advisor					
A vet					
An additional vet or vets for a second opinion					
Social Media e.g. (Facebook,					

WhatsApp, Twitter)					
Internet (other than social media e.g., google)					

Q25. Please indicate how strongly you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I feel under pressure from my vet to reduce antibiotic use on my farm					
Communication between my vet and I is good					

Q26. Do you have a farm advisor?
If you answer '***Yes'*** please go to **Q27**.
If you select ***'No***, please go to **Q29.**

Yes	
No	

Q27. What services do you avail of from your farm advisor? (tick as many as applicable)

To get advice on herd health management	
To get advice on reducing antibiotic use	
To plan vaccine programmes	
To make herd health plans	
To make a biosecurity plan	
To get nutrition advice	
To attend a discussion group	
None of the above	
Other (please specify)	

Q28. Please indicate how strongly you agree or disagree with the following statement.

	Strongly	Disagree	Neither Agree nor	Agree	Strongly

	Disagree		Disagree		Agree
I feel under pressure from my farm advisor to reduce antibiotic use on my farm					

Q29. How often do you **get advice from other farmers** on the following? e.g. In conversation/discussion groups/online.

	Never	Rarely	Sometimes	Frequently	Always
Herd health management					
Reducing antibiotic use					
Animal Vaccine programmes					
Biosecurity on the farm					
Treating sick animals					
Animal Nutrition					

Q30. Please indicate how strongly you agree or disagree with the following statements.

	Strongly Disagree	Disagree	Neither Agree nor Disagree	Agree	Strongly Agree
I feel under pressure from consumers to reduce antibiotic use on my farm					
I feel under pressure from the Department of Agriculture (DAFM/DAERA) to reduce antibiotic use on my farm					
Hearing from other farmers about their experiences influences my decisions around antibiotics					

Q31. Have you ever learned about antibiotic resistance during formal education/training?

Yes	
No	

Q32. Have you ever been to an online or in-person event (e.g., webinar, conference, farm walk) where antibiotic resistance on farms was discussed?

Yes	
No	

Q33. Are you currently a member of a farm advisor led/ facilitated discussion group?

Yes	
No	

Q34. Have you ever looked for information on antibiotic resistance from…? *(please select as many as applicable)*

A discussion group	
A conference	
A farm walk	
A newspaper	
A webinar	
Social media	
The internet (other than a webinar or social media)	
None of the above	
Other (please specify)	

Q35. Please rate your level of agreement with the following statements:

Compared to before the COVID-19 Pandemic…

	Strongly Disagree	Disagree	Neither Agree nor disagree	Agree	Strongly Agree
…I am now more aware of antibiotic resistance					
… I am now more likely to take action to reduce the use of antibiotics on my farm					
…I am now more aware of the connection between animal health and human health					

Q36. In what capacity do you work on the farm? (Full-time = >26 h/week **OR** Part-time = <26h/week)

Full-time	
Part-time	

Q37. Do you have a job off the farm?

Yes	
No	

Q38. How many years of farming experience do you have within your sector?

Q39. How many people work on the farm full time, (including yourself, if you work full time)? *(Full-time = >26 h/week)*

Q40. How many people work on the farm part time (include yourself if you work part time*)? (Part-time = <26h/week)*

Q41. Is there a succession plan in place for your farm?

Yes	
No	
In the process of doing one	
Don't know	
Prefer not to answer	

Q42. What is your gender?

Male	
Female	
Other	

Q43: What is your marital status?

Married	
Single (never married)	
Widowed	
Divorced	
Separated	
Living with partner	
Prefer not to say	

Q44. What is your highest level of agricultural education or training?

One/two-year certificate in agriculture (e.g., green cert)	
Short term agricultural training, less than 60 hours	
Short term agricultural training, more than 60 hours	
Third level degree in agriculture	
None	

Other (7)	
Prefer not to answer	

Q45. In which region is your farm based?

Northern Ireland	
Republic of Ireland	

Q46. What is the total annual income of your household from all sources before any tax and national insurance contributions?
If you share your household with individuals unrelated to you (not a family member or your partner), please count only your personal income. **Include all income from on-farm and off-farm employment and benefits.**

If you are not sure of your household income, please estimate.
Northern Ireland

Under £10,000 per annum	**SD 8**
£10,001 - £20,000 per annum	
£20,001 - £30,000 per annum	
£30,001 - £40,000 per annum	
£40,001 - £50,000 per annum	
£50,001 - £60,000 per annum	
£60,001 - £70,000 per annum	
£70,001 - £80,000 per annum	
£80,001 - £90,000 per annum	
£90,001 - £100,000 per annum	
£100,001 - £150,000 per annum	
£150,001 - £200,000 per annum	
£200,001 - £500,000 per annum	
£500,001 or more	
Prefer not to answer	

Republic of Ireland

Less than €20,000 per annum	
€20,001 – €40,000 per annum	
€40,001 – €60,000 per annum	
€60,001 – €80,000 per annum	
€80,001 – €120,000 per annum	
€120,001 – €160,000 per annum	
€160,001 - €200,000 per annum	
€200,001 - €400,000 per annum	
€400,001 - €800,000 per annum	
€800,001 or more per annum	
Prefer not to answer	

1. Please provide your email address to receive your e-Voucher.

2. If you do not have an email address, please provide your address to receive your voucher.

Thank you for taking the time to complete the survey!

Appendix 3: Study 2

Appendix 3a: Vet recruitment

Vets Invite Draft (Email/social media)

"Queen's University Belfast are conducting a survey to better understand the use of antibiotics in livestock farming and it is really important that we hear the views and opinions of vets like you. As a vet your participation will be extremely helpful in providing us with valuable information.

We therefore invite you to take part in our two-part survey which is completely confidential.

1. Online survey taking approx. 10-15 mins to complete
2. Telephone survey lasting approx. 20 mins

Depending on the focus of your farm animal work please follow the relevant link below:

If most of your farm animal work is focused on **dairy cattle**, please use the following link https://www.surveymonkey.co.uk/r/FVLHW5F, please contact sfarrell11@qub.ac.uk to arrange a time that best suits you to complete the follow up interview.

At the end of the survey, you will be prompted to provide your contact details using a separate link for the follow up telephone survey. Your participation is greatly appreciated."

Appendix 3b: Participant information sheet

Participant information sheet – V2 29/10/2020

Research Project Title

Knowledge, attitudes and behaviour of farmers and vets in relation to antimicrobial use in livestock

You are being invited to take part in this research project. Before you decide to do so, it is important that you understand why this research is being conducted and what it will involve. Please take some time to read the following information carefully. Please email me at sfarrell11@qub.ac.uk if you have any questions or if you would like more information. Thank you for your time.

The purpose of this research

This research project aims to investigate veterinarians' understanding of antibiotics. It will also explore perceptions, attitudes and opinions that influence behaviours towards antibiotic usage in livestock. The project will build upon other research carried out and has been designed to allow comparisons with previous findings, to better understand the behaviours in relation to antibiotic usage on farms.

Why have you been invited to take part?

You have been chosen as you are involved in the care of livestock. It is important to explore your perception, attitudes, knowledge, and opinions in relation to antibiotics, to obtain a better understanding on what influences your behaviour surrounding antibiotic usage.

Do I have to take part?

It is up to you whether or not to take part. You can change your mind and withdraw at any stage. If you do decide to take part, you will be able to keep a copy of this information sheet. **At the beginning of the study you will be asked to provide your own unique 4-digit ID code**. Your data will only be identified by the 4-digit code you provide which only the researcher has access to. Meaning your information is pseudonymous for the purposes of withdrawal, only the researcher will be able

to link you to your data. It is **important that you keep/ remember the unique code you provided** as if you want to withdraw your response from the database you will have to contact researcher Sarah Farrell (sfarrell11@qub.ac.uk) or Claire McKernan (c.mckernan@qub.ac.uk) and provide your unique code. Responses must be withdrawn within 2 weeks of survey completion, as data will be aggregated. You do not need a reason for withdrawing and this will have no effect on any future relationships with Queen's University Belfast.

Should you wish to take part in the survey via skype/teams you will be invited to a private room to take part, and the discussion will be recorded using either Skype or Teams software. You will not be able to record the discussion, only the researcher will be able to record the discussion. Should you wish to take part in the survey via telephone call, a separate recording device will be used. Again, all personal information will not be included in any transcriptions and your identity will remain confidential.

What will happen if I take part?

You will be asked to take part in a short online survey consisting of a series of questions lasting approximately 10-15 minutes. Followed by a telephone survey consisting of a series of questions lasting approximately 20 minutes.

What do I have to do?

Before taking part, it is vital that the consent form is completed electronically for the online survey and verbally for the interview-based survey. Please answer all the questions as openly and honestly as possible. Questions are based on attitudes and perceptions, there are no right and wrong answers. At the beginning of the online survey you will be required to provide some general demographic information. If you feel uncomfortable answering these questions you have the option to select 'prefer not to say'. There are no other commitments associated with participation. For the telephone call or video conferencing recording (Teams or skype), the discussion will be audio recorded, and the anonymised transcripts of the audio recordings will be used by the researchers working on this project. Once transcribed, the original recording will be permanently deleted from research folder and software storage. This transcription will be completed by a professional transcription service and analysed using N-Vivo or similar software, which will be checked by the research team for accuracy. Your identity will not be compromised as only the unique code you provide will be used to identify the transcript. The data you provide will be stored in a password protected file on university premises, all data will be kept for no longer than is necessary and will be destroyed after this time.

What are the possible disadvantages and risks of taking part?

We do not anticipate that you will experience any negative effects from taking part in this survey.

What are the possible benefits of taking part?

This work will have a beneficial impact within this field by contributing to findings that may be used to better farming practices and aid the reduction of antibiotic use on Irish and Northern Irish farms.

What if something goes wrong?

If you have any concerns about any aspects of the study, you can contact the Chief Investigator, Professor Moira Dean. Should you remain unhappy and wish to make a formal complaint, you can contact the Research Governance Team at Queen's University Belfast (Telephone: 028 9097 2529; Email: researchgovernance@qub.ac.uk).

Will my information be confidential if I take part in this project?

All the information collected about you during the course of the research will be kept strictly confidential, as your data will only be identified by the **unique code you provided** which only the researcher has. You will not be able to be identified or identifiable in any reports or publications. Any data collected about you during the survey will be stored in accordance with the General Data Protection Regulation 2016/679. Data collected may be shared in an anonymous form to allow reuse by the research team and project partner Teagasc. These anonymised data will not allow any participants to be identified or identifiable.

What will happen to the results of the research project?

Results of the research will be published. You will not be identifiable in any report or publication.

Who is funding this research?

The project is funded by DAERA postgraduate studentships and Safefood Ireland.

Contacts for further information

Sarah Farrell, School of Biological Sciences, Queen's University Belfast, Northern Ireland. Email: sfarrell11@qub.ac.uk

Dr. Claire McKernan, School of Biological Sciences, Queen's University Belfast, Northern Ireland. Email: c.mckernan@qub.ac.uk

Professor Moira Dean, School of Biological Sciences, Queen's University Belfast, Northern Ireland. Email: moira.dean@qub.ac.uk

The School of Biological Sciences Office, 19 Chlorine Gardens, Belfast, BT9 5DL, Northern Ireland. Tel: +44 (0)28 9097 5787, email: biolsci@qub.ac.uk

Appendix 3c: Veterinarian online survey

Q1. In which county is your practice located?

Prefer not to say

Q2. How much of your time do you dedicate to the following species? (estimated percentage of time %)

Farm animals		
Companion animals		>40% CLOSE
Equine		>40% CLOSE
Other		>40% CLOSE

Q3. Please indicate in which agricultural sector do you work in? (select as many as applicable)

Beef	
Dairy	
Porcine	
Poultry	
Sheep	
Other	

Q4. What sector is the main focus of your farm animal work? (select as many as applicable)

Beef	
Dairy	
Porcine	
Poultry	
Sheep	
Mixed	

Q5. Please indicate your level of employment. (Full-time = >26 h/week <u>OR</u> Part-time = <26h/week)

Full-time		
Part-time		
Prefer not to say		

Q6. What is your age?

<18, CLOSE

Q7. How many years of veterinary experience do you have practicing veterinary medicine?

0-10 years	
11-20 years	
20+ years	
Prefer not to say	

Q8. How many vets are currently working in your practice? (fulltime/part time) (Full- time equivalent = 1 person and an individual working on Part-time basis =0.5)

Prefer not to say	

Q9. Please indicate your involvement in the practice.

Practice owner/partner	
Employee	
Locum	
Other … (*please specify*)	
Prefer not to say	

Q10. I identify my gender as:

Male	
Female	
Other	
Prefer not to say	

Q11. Please indicate whether you think the following statements are true or false:

	True	**False**
Antibiotics are used to cure infections caused by viruses		
Bacteria can become resistant to antibiotics when antibiotics are frequently used		
Overuse of antibiotics can lead to antimicrobial resistance		
Misuse of antibiotics can lead to antimicrobial resistance		
Certain antibiotics are reserved for human use		

Q12. On a scale of 1 – 7, where 1 is highly skilled and 7 is unskilled, how equipped do you feel to do the following:

	1= Unskilled	2	3	4	5	6	7=Very skilled
I am able to identify the correct antibiotic for infection.							
I am able to calculate the correct dose of antibiotics for animals							
I am able to calculate and administer the correct duration the antibiotics are used for							
I am able to record relevant antibiotic usage information for each farm within my practice							
I am able to monitor and record antibiotic use within my practice							
I am able to comply to antibiotic protocols when treating animals							
I am able to educate farmers on the use of alternative therapies to treat common diseases on their farm (e.g. vaccines, anti-inflammatories)							

Q13. Please indicate your agreement with the following statements

I Intend to …	Strongly Disagree	Disagree	Somewhat Disagree	Neither	Somewhat Agree	Agree	Strongly Agree
…Reduce antibiotic use in my practice	1	2	3	4	5	6	7
…Use antibiotics responsibly in my practice	1	2	3	4	5	6	7
…Adhere to antibiotic selection protocols and recommendations before prescribing antibiotics (e.g. susceptibility and diagnostic testing)	1	2	3	4	5	6	7
…Encourage the implementation of alternative methods to using antibiotics e.g. use of vaccines or herd health planning	1	2	3	4	5	6	7

Q14. Please indicate your agreement with the following statements

How concerned are you about antimicrobial resistance for…	Not at all concerned			Neutral			Extremely concerning
…humans	1	2	3	4	5	6	7
… animals	1	2	3	4	5	6	7

Q15. On a scale of 1 to 7, how helpful do you think the following strategies would be to encourage good antibiotic practice on farms?

	Very unhelpful			Neither			Very helpful
Put in place new policies and regulations to restrict antibiotic use	1	2	3	4	5	6	7
Implement legal action should policies and legislation not be adhered to	1	2	3	4	5	6	7
Provide financial incentives or grants to support the use of alternatives to antibiotics such as herd health planning, vaccines etc.	1	2	3	4	5	6	7
Uncoupling veterinary prescribing from the sale of antimicrobials	1	2	3	4	5	6	7
Provide educational training programs for all farmers on antibiotics and preventing infectious disease	1	2	3	4	5	6	7
Provision of tailored herd health plans and routine visits for clients	1	2	3	4	5	6	7
Assign one contracted vet to a farm	1	2	3	4	5	6	7
Publish antibiotic usage data on each farm 2 times a year	1	2	3	4	5	6	7

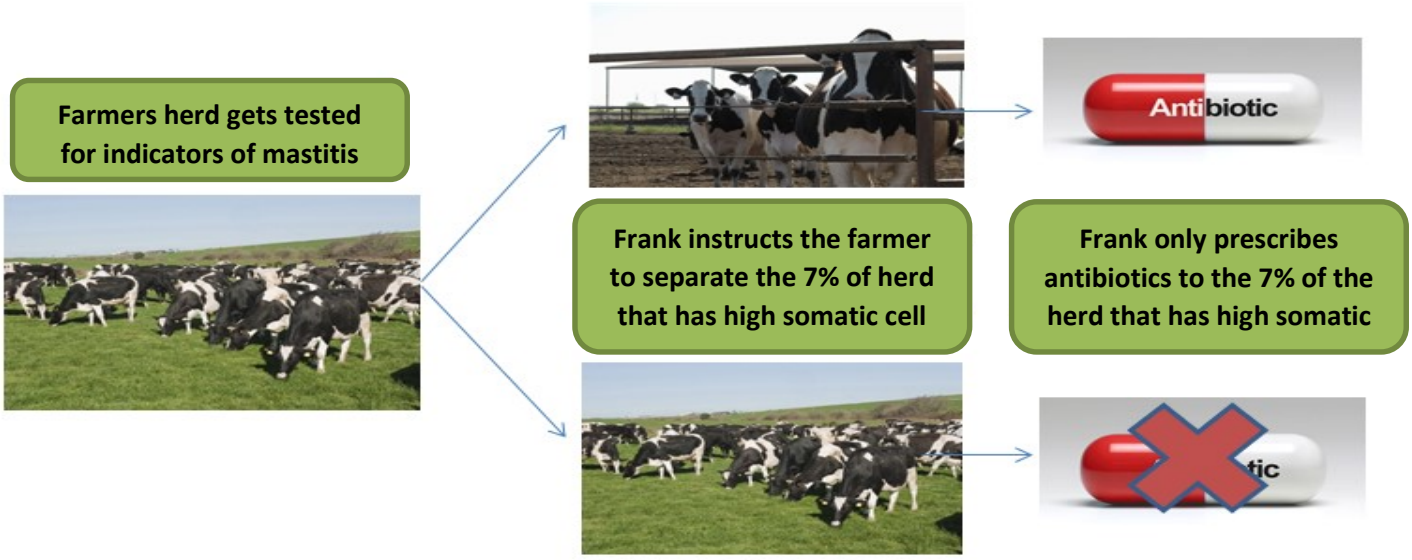
Improve diagnostic and susceptibility testing procedures	1	2	3	4	5	6	7
Provide training and support to improve communication skills of vet	1	2	3	4	5	6	7
Compulsory CPD for veterinarians on antimicrobial use	1	2	3	4	5	6	7
Mandatory antibiotic use recording for farms	1	2	3	4	5	6	7
Mandatory antibiotic prescribing recording for veterinary practices	1	2	3	4	5	6	7

Q16. What strategy do you feel would be the most effective in encouraging good antimicrobial practice? And Why?

Q17. What strategy do you feel would be the least effective in encouraging good antimicrobial practice? And Why?

Please answer the following questions, keeping in mind the scenario provided below

Frank is a vet and his client is a dairy farmer getting ready to dry off his herd. Together with his client, they discuss the latest milk recordings for the herd. Only 7% of cows have high cell counts. Frank decides to prescribe the high cell count cows with dry cow antibiotic tubes but does not give antibiotic treatment to the remaining herd.



Q18. How often do you make similar decisions to Frank in your practice?

Q19. What are your views on these treatment plans?

Q20. What would make you encourage a farmer to go down this treatment route?

Q21. What, If anything, would stop you from going down this treatment route?

Q22. What alternative treatment plans would you consider? And Why?

Q23. How do you feel about suggesting treatment options to farmers that do not involve antibiotics?

Appendix 3d: Veterinarian interview schedule

Telephone Interview Questions

Q1. What do you think are the consequences of antimicrobial resistance?

Q2. Who do you feel is responsible for antimicrobial resistance?

Q3. What do you think are the ***benefits*** associated with reducing antimicrobial use on farms?

Q4. What do you think are the ***risks*** associated with reducing antimicrobial use on farms?

Q5. How do you view your professional responsibility towards antimicrobial use and antimicrobial resistance?

Q6. How would you describe your access to laboratory (susceptibility/diagnostic) testing?

Q7. How would you describe your access to training focused on antimicrobials?

Q8. Do you have access to peer support in relation to reducing antimicrobial use?

Q9. How do your superiors influence your prescribing behaviour, if at all?

Q10. What do you think your peer's views on antimicrobial use and antimicrobial resistance are?

Q11. Whose advice and opinion do you most respect around antimicrobial usage? And why?

Q12. What are your experiences of client pressure and prescribing treatment plans?

Q13. What do you think would help improve the relationship between farmers and vets when it comes to reducing antibiotics?

Appendix 3e: COREQ Checklist for veterinarian interview

Consolidated criteria for reporting qualitative studies (COREQ): 32-item checklist

Developed from:
Tong A, Sainsbury P, Craig J. Consolidated criteria for reporting qualitative research (COREQ): a 32-item checklist for interviews and focus groups. *International Journal for Quality in Health Care*. 2007. Volume 19, Number 6: pp. 349 – 357

No. Item	Guide questions/description	Response
Domain 1: Research team and reflexivity		
Personal Characteristics		
1. Inter viewer/facilitator	Which author/s conducted the interview or	SF

	focus group?	
2. Credentials	What were the researcher's credentials? E.g. PhD, MD	MSci
3. Occupation	What was their occupation at the time of the study?	PhD Student
4. Gender	Was the researcher male or female?	Female
5. Experience and training	What experience or training did the researcher have?	Attended training sessions on interviewing and previously observed focus groups
Relationship with participants		
6. Relationship established	Was a relationship established prior to study commencement?	**No**
7. Participant knowledge of the interviewer	What did the participants know about the researcher? e.g. personal goals, reasons for doing the research	Participants knew that the researcher was a PhD student at QUB and that the reason for the research was to gain a better understanding of AMU on dairy farms.
8. Interviewer characteristics	What characteristics were reported about the inter viewer/facilitator? e.g. Bias, assumptions, reasons and interests in the research topic	None

Domain 2: study design		
Theoretical framework		
9. Methodological orientation and Theory	What methodological orientation was stated to underpin the study? e.g. grounded theory, discourse analysis, ethnography, phenomenology, content analysis	COM-B model was applied to the interview findings. Thematic analysis was used to derive codes and theme from the interview data.
Participant selection		
10. Sampling	How were participants selected? e.g. purposive, convenience, consecutive, snowball	Purposive sampling to recruit dairy veterinarians.
11. Method of approach	How were participants approached? e.g. face-to-face, telephone, mail, email	Due to external organizations assisting with recruitment the exact number of participants approached is unknown however all participants were approached via email.
12. Sample size	How many participants were in the study?	**26 survey participants, then 12 of that 26 completed follow up interviews.**
13. Non-participation	How many people refused to participate or dropped out? Reasons?	**14 of the survey participants did not express interest in completeing follow up interview. Exact number of veterinarians cannot be knows due to number of external sources used to try and recruit participants.**
Setting		
14. Setting of data collection	Where was the data collected? e.g. home, clinic, workplace	**Via telephone, while the researcher**

		worked from home due to covid-19 restrictions.
15. Presence of non-participants	Was anyone else present besides the participants and researchers?	**No**
16. Description of sample	What are the important characteristics of the sample? e.g. demographic data, date	**Sample consisted only of veterinarians whose farm animal work consisted mainly of dairy cattle.**
Data collection		
17. Interview guide	Were questions, prompts, guides provided by the authors? Was it pilot tested?	**A semi-structured interview guide was created.** **The interview was pilot tested before data collection began.**
18. Repeat interviews	Were repeat interviews carried out? If yes, how many?	**No repeat interviews were conducted**
19. Audio/visual recording	Did the research use audio or visual recording to collect the data?	**Interviews were audio recorded**
20. Field notes	Were field notes made during and/or after the interview or focus group?	**No as audio recordings were made**
21. Duration	What was the duration of the interviews or focus group?	**Interviews lasted between 30-45 minutes**
22. Data saturation	Was data saturation discussed?	**Yes data saturation was discussed and it was decided after 12 interviews saturation had been reached**
23. Transcripts returned	Were transcripts returned to participants for comment and/or correction?	**No**
Domain 3: analysis and findings		
Data analysis		
24. Number of data coders	How many data coders coded the data?	**Two**
25. Description of the coding tree	Did authors provide a description of the coding tree?	**No**
26. Derivation of themes	Were themes identified in advance or derived from the data?	**Derived from the data**
27. Software	What software, if applicable, was used to	**Nvivo 12 software**

	manage the data?	
28. Participant checking	Did participants provide feedback on the findings?	**No**
Reporting		
29. Quotations presented	Were participant quotations presented to illustrate the themes/findings? Was each quotation identified? e.g. participant number	**Yes**
30. Data and findings consistent	Was there consistency between the data presented and the findings?	**Yes**
31. Clarity of major themes	Were major themes clearly presented in the findings?	**Yes**
32. Clarity of minor themes	Is there a description of diverse cases or discussion of minor themes?	**Yes**

Appendix 4: Study 3

Appendix 4a: Participant information sheet for dairy stakeholder workshop

Title of study: Knowledge and attitudes of local veterinary practitioners and dairy farmers to antimicrobial resistance (AMR)

1. Invitation Paragraph

You are being invited to take part in a research study. Before you decide whether or not to take part it is important that you understand why the research is being done and what it will involve. Please take some time to read the following information carefully. Please email me at sfarrell11@qub.ac.uk if you have any questions or if you would like more information. Thank you for your time.

2. What is the purpose of the study?

This study aims evaluate proposed behaviour change interventions to promote more responsible use of antimicrobials within the dairy industry in Northern Ireland. Following analysis of data collected from dairy farmers and veterinarians on the Island of Ireland, potential behaviour change interventions have been proposed to help farmers and veterinarians overcome current barriers faced when trying to reduce their antimicrobial use on farms. This follow up study will determine how key stakeholders of the NI dairy industry perceive the proposed interventions in terms of their acceptability, practicability, effectiveness and affordability.

3. Why have I been chosen?

You have been chosen because as a crucial stakeholder in the NI dairy industry, your evaluation of the proposed behaviour change interventions will help us to put forward evidence-based

interventions which are more likely to help farmers and veterinarians achieve responsible antimicrobial use on NI dairy farms.

4. Do I have to take part?

It is up to you whether or not to take part. If you do decide to take part, you will be able to keep a copy of this information sheet and a consent form will be provided to you prior to the commencement of the workshop. You can withdraw from the workshop at any time. You can withdraw from the study up to two weeks following the workshop. You do not need to give a reason. You will be asked to create a unique ID code at the beginning of the workshop which will only be identifiable to the researcher to enable withdrawal from the study if you wish to do so. The ID code will be generated using the first letter of the town you were born, the last two digits of your telephone number and the first letter of the primary school you attended.

5. What will happen to me if I take part?

You will be asked to attend a workshop at Greenmount campus. The workshop will last 2-3 hours and will involve evaluating and discussion of the proposed behaviour change interventions following a short presentation summarising the findings of the previous survey and interview data obtained from dairy farmers and veterinarians

6. What are the possible risks or disadvantages of taking part?

Participating in this research is not anticipated to cause you any disadvantages or discomfort.

7. What are the possible benefits of taking part?

Whilst there are no immediate benefits for participants, this work will have a beneficial impact within this field by contributing findings that may be used to better farming practices and aid the reduction of antibiotic use on dairy farms.

8. What if something goes wrong?

If you have any concerns about any aspects of the study, you can contact the Chief Investigator, Prof. Moira Dead (email: moira.dean@qub.ac.uk). Should you remain unhappy and wish to make a formal complaint, you can contact the Research Governance Team at Queen's University Belfast (Telephone: 028 9097 2529; Email: researchgovernance@qub.ac.uk).

9. Will my taking part in this study be kept confidential?

All the information collected about you during the course of the research will be kept strictly confidential. You will not be able to be identified or identifiable in any reports or publications. Any data collected about you during the workshop will be stored on the researcher's computer in a form protected by passwords and other relevant security processes and technologies. The computer will remain in a locked room. Data collected may be shared in an anonymous form to allow reuse by the

research team and other third parties. These anonymised data will not allow any participants to be identified or identifiable.

10. Will I be recorded, and how will recorded media be used?

You will be recorded in order for the workshop discussions to be transcribed. They will be used for transcription purposes only and will remain confidential. Once transcribed, audio recordings will be destroyed. Audio recordings and transcripts will be stored online in a form protected by passwords and other relevant security processes and technologies.

11. What will happen to the results of the research?

Results of the research will be published. You will not be identifiable in any report or publication. If you wish to obtain a copy of the results you may contact a member of the research team.

12. Who is organising and funding the research?

This research is part of a DAERA (Department of Agriculture, Environment and Rural Affairs) funded PhD studentship.

13. Who has reviewed the study?

This study has been reviewed and granted ethical approval by the Faculty of Medicine, Health and Life Science Research Ethics Committee.

14. Contact for Further Information

Sarah Farrell, School of Biological Sciences, Queen's University Belfast, Northern Ireland. Email: sfarrell11@qub.ac.uk

Professor Moira Dean, School of Biological Sciences, Queen's University Belfast, Northern Ireland. Email: moira.dean@qub.ac.uk

The School of Biological Sciences Office, 19 Chlorine Gardens, Belfast, BT9 5DL, Northern Ireland. Tel: +44 (0)28 9097 5787, email: biolsci@qub.ac.uk

Thank you for your interest in this study and for taking the time to read through this information sheet.

Appendix 4b: Workshop presentation

Department of Agriculture, Environment and Rural Affairs
www.daera-ni.gov.uk

QUEEN'S UNIVERSITY BELFAST

Behaviour change interventions t
promote responsible antibiotic us
on dairy farms

Aim of current PhD project

- Explore perceptions of dairy farmers and vets relating to AMU and AMR
- Determine the current barriers and facilitators to responsible AMU on dairy farms
- Propose behaviour change interventions to overcome barriers and promote more responsible AMU on dairy farms

Research to date

- Online survey n=240 dairy farmers
- Telephone interview n=12 dairy vets

- Identified factors influencing antibiotic use on dairy farms
- Determine predictors of responsible antibiotic use behaviour

Factors influencing AMU on dairy farms

Awareness of AMR

Pressure to reduce AMU

Resources to facilitate reduced AMU

Concerns for animal welfare

Social influences on AMU

Confidence in ability to reduce AMU

Knowledge of reduced AMU

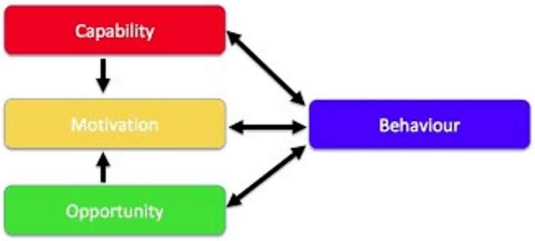
Farmer & vet working relationship

COM-B Model of behaviour change

Behaviour is a result of an individuals Capability, Opportunity & Motivation to perform the behaviour

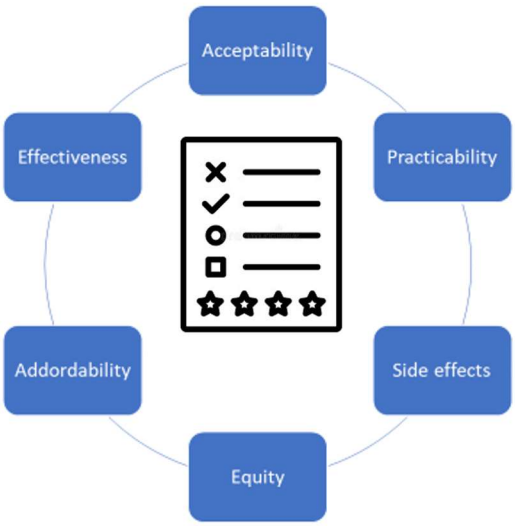
Factors influencing AMU in dairy farming mapped to the COM -B model

Behaviour change wheel then Identified types of intervention to overcome current barriers & facilitate responsible AMU



Assessment of proposed interventions (APEASE)

- Used to evaluate behaviour change interventions on a number of criteria
- Determine which behaviour change interventions are most feasible and acceptable



Facilitated discussion groups

- Stakeholder will first individually assess the 10 proposed interventions using the APEASE criteria
- In groups stakeholders will discuss their reasons for ratings– pros and cons of each intervention, what might improve intervention?, who should be responsible for implementing? Any other steps that might be successful in promoting responsible AMU on dairy farms?

Appendix 4c: Discussion topic guide

In groups participants will discuss the 10 interventions proposed. Facilitators will guide participants in groups through each of the interventions, for each intervention please ask participants to briefly explain their reasoning behind their rating.

1. Pros of intervention 2. Drawbacks of intervention 3. What could help overcome problems perceived with intervention? 4. Who should be responsible for implementing the intervention? 5. How can implementation be fast tracked?

After all interventions have been discussed, ask if they can think of any other possible options which they feel may help achieve reduced AMU.
Aim to spend a **maximum of 10 minutes per intervention**. You can use the table below to tick off each discussion part.

Intervention:	**Pros**	**Draw-backs**	**Overcome problems**	**Respons-ibility**	**Fast track?**
Farmer education program to improve awareness of their role in AMR					
Training to impart skills needed by farmers to reduce antibiotic use while maintaining herd health & productivity					
Farmer peer information sharing groups for farmers to share experiences of reducing antibiotic use successfully with their peers to encourage others to act					
Positive reinforcement & feedback programs to build farmers confidence in their ability to reduce antibiotic use safely on their farms					
Vet training to enable them to educate farmers on AMR and help encourage farmer behaviour change					
Mandatory vet training on AMR and how to reduce the need for use on dairy farms					
Legislation/guidelines for one vet per farm at any one period of time for antimicrobial prescriptions					
Removal of profit from veterinary antimicrobial sales					
Provision of rapid (potentially on farm) susceptibility & diagnostic testing for dairy cattle					
Vet peer information sharing groups where vets can share knowledge and experiences of working with farmers to successfully reduce AMU on farm					

Are there any other potential interventions not covered here that you feel might help achieve reduced/more responsible AMU on dairy farms?