An interdisciplinary approach to understanding antimicrobial use on sheep and beef farms in the UK

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Abstract

There is currently a lack of evidence on: how antimicrobials are used on sheep and beef farms in the UK, the presence of antimicrobial resistance in sheep and beef cattle, and farmer and veterinarian decision-making around antimicrobial use in sheep and beef cattle. This thesis comprises of seven studies which attempt to address these evidence gaps using a multidisciplinary, mixed-methods approach.

Study 1 used a mixed-methods approach to evaluate farmers' antimicrobial recording against the contents of medicine bins. Results showed that the medicine records may be inaccurate and measured less antimicrobials than the medicine bins. Study 2 used disk diffusion testing and different interpretation methods to identify patterns of antimicrobial resistance on sheep and beef farms in England and Wales. The key findings were that antimicrobial resistance appears to be low, and the use of species-specific cut-off values may be more appropriate for interpretation of non-susceptible isolates compared with clinical breakpoints. Study 3 was a factorial survey to assess the factors that influence veterinarians' decisions to prescribe antimicrobials to sheep and beef farmers. The main finding was that confidence in the farmer's judgement of disease had the largest influence on the veterinarians' decision to prescribe.

The final four studies investigated farmers' decision-making around antimicrobials. Study 4 was a survey of beef farmers in England and Wales. The key conclusion was that although self-reported antimicrobial use appeared to be low, some gaps in farmers' knowledge around antimicrobial use were identified. Study 5 was a survey of sheep farmers in the UK. The important findings were that farmers' who carried out traditional practices and did not carry out modern practices were more likely to have attitudes towards antimicrobials that do not align with current recommendations. Study 6 used a mixed-methods approach to understand why farmers use, or do not use, prophylactic antimicrobials to prevent neonatal lamb diseases. Key findings were that oral antimicrobials were dissociated from parenteral antimicrobials and farmers perceived that control of neonatal disease was due to luck or chance. Farmers who used antimicrobials for treatment of disease were influenced by social pressures; whereas, farmers who routinely used prophylactic antimicrobials did so due to anticipated regret and experiential avoidance. Study 7 used qualitative interviews to understand sheep and beef farmers' perceptions of risk around antimicrobial use and resistance. The main findings were that respondents reported not having the technical knowledge and skills needed to measure antimicrobial use and resistance and were concerned that reducing their antimicrobial use would have negative consequences. Farmers put the responsibility for managing

antimicrobial use on their veterinarian and blamed other farmers for antimicrobial resistance.

Across the studies, the importance of recording and interpreting data was highlighted as a common theme. Common factors which influenced farmers' decision-making were also identified including: identity, experience, social norms, capability, responsibility and emotion. Further research should seek to incorporate these decision-making factors into behaviour-change interventions to improve farmers' antimicrobial use behaviours. The findings of this research have important industry and policy implications in terms of how antimicrobial use targets are set and how antimicrobial use and resistance should be measured on sheep and beef farms.

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Declaration

I declare that the work in this thesis was carried out in accordance with the regulations of the University of Nottingham. The work is original and no part of the thesis has been submitted for any other academic award. Any views expressed in the thesis are those of the author. This work includes studies which have been published in peer-reviewed journals, as indicated in the text. Except where it states otherwise by reference or acknowledgment, the work presented is entirely my own. This work was funded by the Agriculture and Horticulture Development Board.

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I. Contents

1. General Introduction 1
   1.1. AMU and AMR surveillance and policy in the veterinary sector 2
      1.1.1. UK AMU surveillance and data 2
      1.1.2. AMU surveillance in other countries 4
      1.1.3. AMR surveillance in the UK 4
      1.1.4. AMR surveillance in other countries 6
   1.2. AMU and AMR in the sheep and beef livestock sectors 6
      1.2.1. Types of AMU in livestock 6
      1.2.2. Antimicrobial prescribing regulations in the UK 7
      1.2.3. AMU and resistance in the UK sheep and beef industry 8
   1.3. Antimicrobial decision-making 11
      1.3.1. Veterinarian decision-making 11
      1.3.2. Farmer decision-making 14
      1.3.3. Lessons from human medicine decision-making 17
   1.4. Gaps in the research 19
   1.5. Aims of the thesis 20
      1.5.1. Overview of chapters 20
2. Introduction to methods 24
   2.1. Evaluation of farmers' antimicrobial recording 24
      2.1.1. Data collection methods 24
      2.1.2. Quantification indicators 27
   2.2. Antimicrobial susceptibility testing 31
      2.2.1. Sampling 31
      2.2.2. Phenotypic methods 32
      2.2.3. Choice of antimicrobial agents 32
      2.2.4. Interpretation of inhibition zones 33
   2.3. Social science methods 34
      2.3.1. Use of psychological theory to understand behaviour 34
      2.3.2. Use of sociological theory to understand behaviour 36
      2.3.3. Grounded theory 37
      2.3.4. Survey methods 38
      2.3.5. Text analysis 41
      2.3.6. Semi-structured interviews 44

2.3.7. Mixed methods research 47
2.4. Methods used for the project 49
2.4.1. Target and source populations for the studies 51
2.4.2. Longitudinal study design 54
3. Study 1: Evaluation of the use of antimicrobial bins and medicine records to quantify AMU on sheep, beef, and mixed species farms 56
3.1. Abstract 56
3.2. Introduction 56
3.3. Methods 59
3.3.1. Participant recruitment 59
3.3.2. Ethics 59
3.3.3. Study design 59
3.3.4. Collection of AMU 59
3.3.5. Quantitative data analysis 60
3.3.6. Qualitative data analysis 62
3.3.7. Integration of quantitative and qualitative data 62
3.4. Results 63
3.4.1. Quantitative evaluation 63
3.4.2. Qualitative evaluation 68
3.4.3. Integration of results 74
3.5. Discussion 75
3.5.1. Limitations 77
3.6. Conclusions, research and industry implications 78
3.7. Impact of Covid-19 79
4. Study 2: AMR patterns on sheep and beef farms in England and Wales: A comparison of disk diffusion interpretation methods 80
4.1. Abstract 80
4.2. Introduction 80
4.3. Materials and Methods 82
4.3.1. Participant recruitment 82
4.3.2. Ethics 83
4.3.3. Sample collection 83
4.3.4. Isolation of *Escherichia coli* 83
4.3.5. Antimicrobial susceptibility testing 83
4.3.6. Terminology 84
4.3.7. Data analysis 84

4.4. Results 87
4.4.1. Comparison of methods to interpret resistance 88
4.4.2. Farm level susceptibility 90
4.4.3. Cluster analysis 91
4.4.4. Multilevel logistic regression model 92
4.5. Discussion 94
4.5.1. Limitations 98
4.6. Conclusions 98
5. Study 3: To prescribe or not to prescribe? A factorial survey to explore veterinarians' decision-making when prescribing antimicrobials to sheep and beef farmers in the UK 99
5.1. Abstract 99
5.2. Introduction 100
5.3. Methods 102
5.3.1. Factorial survey approach 102
5.3.2. Scenario and dependent variables 102
5.3.3. Vignette predictor variables 103
5.3.4. Other predictor variables 105
5.3.5. Study sample and survey distribution 105
5.3.6. Ethics 106
5.3.7. Data analysis 106
5.4. Results 107
5.4.1. Respondent demographics 107
5.4.2. Multilevel models 109
5.5. Discussion 113
5.5.1. Strengths and limitations 116
5.6. Conclusion 117
6. Study 4: AMU practices and perceptions of beef farmers in England and Wales 118
6.1. Abstract 118
6.2. Introduction 118
6.3. Methods 119
6.3.1. Survey design 119
6.3.2. Ethics 120
6.3.3. Survey distribution 121
6.3.4. Data analysis 121

6.3.5. Multivariable logistic regression 121
6.4. Results 122
6.4.1. General farm characteristics 122
6.4.2. Cattle health 123
6.4.3. Knowledge, opinions and perceptions around AMU and AMR 126
6.4.4. Antimicrobial opinion statement ratings 126
6.4.5. Multivariable logistic regression 127
6.5. Discussion 128
6.5.1. Limitations 131
6.6. Conclusion 132
7. Study 5: From the other perspective: Behavioural factors associated with UK sheep farmers' attitudes towards AMU and AMR 133
7.1. Abstract 133
7.2. Introduction 134
7.3. Methods 136
7.3.1. Survey design 136
7.3.2. Distribution of survey 137
7.3.3. Ethics 137
7.3.4. Data analysis 137
7.4. Results 139
7.4.1. Flock productivity 141
7.4.2. Changes in management practices 141
7.4.3. Flock advice 142
7.4.4. AMU practices and perceptions 142
7.4.5. Antimicrobial attitude clusters 142
7.4.6. Multivariable logistic regression model 144
7.5. Discussion 145
7.5.1. Limitations 148
7.5.2. Implications for antimicrobial behaviour change 149
7.6. Conclusion 150
8. Study 6: Understanding farmers' decision-making around prophylactic AMU in lambs: Qualitative analysis and natural language processing of online discussion forums 151
8.1. Abstract 151
8.2. Introduction 152
8.3. Methods 154

8.3.1. Study sample and data collection 154
8.3.2. Ethical considerations 154
8.3.3. Qualitative data analysis: grounded theory 155
8.3.4. Quantitative data analysis: natural language processing content analysis 155
8.3.5. Integration of qualitative and quantitative results 157
8.4. Results 157
8.4.1. Qualitative analysis 157
8.4.2. A theoretical framework for farmers' decision-making around prophylactic AMU in lambs 167
8.4.3. Quantitative analysis: natural language processing content analysis 168
8.4.4. Integration of the quantitative and qualitative analysis 170
8.5. Discussion 172
8.5.1. Good farmer identity 172
8.5.2. Economic constraints and the impact on perceived capability 173
8.5.3. Anticipated regret, negative emotions and experiential avoidance . 175
8.5.4. Perception of social judgement 176
8.5.5. Limitations 176
8.6. Conclusions, research and industry Implications 177
9. Study 7: Farmers' perceptions of preventing AMR on sheep and beef farms: risk, responsibility and action 178
9.1. Abstract 178
9.2. Introduction 178
9.2.1. Risk concepts in social science 180
9.2.2. Risk as part of farmers habitus 181
9.3. Methodology 182
9.3.1. Ethics 183
9.4. Findings 183
9.4.1. Antimicrobial resistance – the script of an emerging threat 183
9.4.2. Good farmer habitus – the script of experienced, knowledgeable farmers 185
9.4.3. Adopting preventative measures – the script of controlling risk and adopting the precautionary principle 187
9.4.4. Taking responsibility for risk – the script of risk, defence and othering 188
9.5. Discussion 192

9.5.1. Implications for policy 198
9.6. Conclusion 199
10. Discussion 200
10.1. Aims of the research 200
10.2. Common themes across the thesis 200
10.2.1. Importance of recording and interpreting data 200
10.2.2. Common decision-making constructs across the thesis 202
10.3. Limitations of the research 214
10.3.1. Validity and representativeness 214
10.3.2. Bias 216
10.4. Policy and industry implications and impact 217
10.4.1. Impact in forming new antimicrobial use targets 217
10.4.2. Implications for knowledge exchange 217
10.4.3. Implications for communication strategies 218
10.4.4. Implications for existing benchmarking strategies 218
10.4.5. Implications for the new antimicrobial recording system 219
10.4.6. Implications for AMR surveillance in sheep and beef cattle 219
10.5. Future directions 220
10.6. Conclusions 221
11. References 222
12. Appendices 263

Index of figures

Figure 1: Diagram of the overview of the thesis structure and how chapters combine to investigate the thesis aims 21
Figure 2: Methods used for each study in the project. 50
Figure 3: Schematic for the study population of studies 1, 2, 4, 5 and 7 52
Figure 4: An overview of the longitudinal study design 55
Figure 5: Adherence of 35 farmers to the antimicrobial record keeping and use of the antimicrobial bin over the study period 63
Figure 6: Scatterplot and line of equality of AMU (mg) measured by bins and medicine records for 30 sheep and beef farms 66
Figure 7: Bland-Altman plot to compare quantities of antimicrobials measured by the bins and medicine records for 30 sheep and beef farms. 67
Figure 8: Percentile differences between the quantities (mg) of antimicrobials measured from the bin and medicine records for the same farm 68
Figure 9: Single-linkage clustering dendrograms for non-susceptibility to eight antimicrobials 92
Figure 10: Example vignette used in the factorial survey 103
Figure 11: Framework obtained from the results of the survey with regards to significant factors associated with the decision to prescribe antimicrobials 113
Figure 12: Antimicrobial classes most commonly used by beef farmers for the treatment of pneumonia (N=132) 125
Figure 13: Theoretical framework based on grounded theory analysis for the prophylactic use of antimicrobials in neonatal lambs. 168
Figure 14: Framework for sheep and beef farmers' AMU decision-making including how the concepts can link together 203

Index of tables

Table 1: An overview of the common methods for collecting AMU on-farm 27
Table 2: Summary of commonly used units that can make up a treatment indicator 30
Table 3: A system to compare qualitative and quantitative results (Adapted from Morgan (2019)) 49
Table 4: Location of farms and number of animals (at time of first visit) on farms taking part in the longitudinal study 53
Table 5: Median AMU and Kendall's T_a correlation by antimicrobial class on thirty farms based on medicine records and antimicrobial bins 65
Table 6: Barriers to using the antimicrobial bin experienced by famers in the study 69
Table 7: Barriers to antimicrobial recording experienced by farmers taking part in the study 72
Table 8: Assessment and integration of qualitative and quantitative results for the evaluation of bins and medicine records as methods of quantification of antimicrobials 74
Table 9: Disk contents used to determine antimicrobial susceptibility of *E. coli* isolates and source of clinical breakpoints 84
Table 10: Metal concentrations of soil from 35 sheep and beef farms based on UK soil observatory data 86
Table 11: Number of presumptive *E. coli* isolates tested for each farm by animal origin 88
Table 12: Epidemiological cut-off values calculated using the NRI method compared with clinical breakpoints and ECOFF values 89
Table 13: Prevalence of antimicrobial susceptible (S) and wild type (WT) presumptive *E. coli* isolated from sheep using clinical breakpoints, ECOFFs and the NRI method . 90
Table 14: Prevalence of antimicrobial susceptible (S) and wild type (WT) presumptive *E. coli* isolated from beef cattle using clinical breakpoints, ECOFFs and the NRI method 90
Table 15: Farm level prevalence of antimicrobial susceptibility of all *E. coli* isolated from sheep and beef farms based on the NRI method and clinical breakpoints 91
Table 16: Univariable multilevel logistic regression analysis for risk factors associated with presumptive *E. coli* defined as non-wild type for tetracycline 93
Table 17: Multivariable multilevel logistic regression analysis for risk factors associated with presumptive *E. coli* isolates being defined as non-wild type for tetracycline 94
Table 18: Variables included in the factorial survey vignettes, and the theoretical constructs they represent 104
Table 19: Descriptive statistics of respondent characteristics 108
Table 20: Random slope and random intercept models to explain the veterinarians' likelihood to prescribe antimicrobials to a sheep and beef farmer vignette ratings (Outcome A) 109
Table 21: Random slope and random intercept models to explain the percentage of veterinarians which respondents expected to prescribe antimicrobials in the vignette situations (Outcome B) 111
Table 22: Beef farmers' ratings for health issues in terms of challenges to their herd (1=Significant health issue, 5=Not a health issue at all) 124
Table 23: Beef farmers' views on a series of statements related to AMU and AMR 127

Table 24: Results of multivariable logistic regression for treatment of over 5% of the herd with antimicrobials for pneumonia (N=129)..... 128
Table 25: Characteristics of the respondents and their farms 141
Table 26: Mean ratings of antimicrobial statements for two clusters of farmers 143
Table 27: Results of multivariable logistic regression for the associations of farmer practices, characteristics and behaviours on farmers belonging to the discordant antimicrobial attitude group compared to the concordant attitude group (N=457) 144
Table 28: LIWC variables used to address the research question (Adapted from Pennebaker et al. (2015b)) 156
Table 29: The categories and sub-categories relating to farmers' decision-making around AMU in neonatal lambs identified from the qualitative analysis..... 157
Table 30: Mean and median scores for the four summary language variables in the study group and the control groups, and the results from the Kruskal Wallis test and post-hoc Dunn's test 169
Table 31: Median and median relative frequencies of words used in the study group and control groups, and the results on the Kruskal Wallis test with post-hoc Dunn's test..... 170
Table 32: Assessment and integration of qualitative and quantitative results to understand farmers' decision-making around routine prophylactic AMU in lambs. 171

Appendices

Appendix 1: Information sheet with consent form for farmers taking part in the longitudinal study (Studies 1, 2, and 7) 263
Appendix 2: Ethics form for studies 1, 2, 3, 4, 5 and 7 267
Appendix 3: Information collected at the end of the longitudinal study (Study 1) .. 279
Appendix 4: Recruitment letter and information sheet for Study 3 281
Appendix 5: Example survey for Study 3 283
Appendix 6: Survey for Study 4 290
Appendix 7: Benjamini-Hochberg corrected p-values with a false discovery rate of 0.1 for the exploratory univariable logistical regression for Study 4 304
Appendix 8: Survey for Study 5 305
Appendix 9: P-values for univariable logistic regression analysis for study 5 with Benjamini-Hochberg corrected p-values based on a false discovery rate of 0.1 346
Appendix 10: Ethics approval form for Study 6 347
Appendix 11: Interview schedule for Study 7 357

Abbreviations

AHDB	Agriculture and Horticulture Development Board
AMR	Antimicrobial resistance
AMU	Antimicrobial use
CH	Chris Hudson
CHAWG	Cattle Health and Welfare Group
CI	Confidence Interval
CIA	Critically important antimicrobial
CLSI	Clinical and Laboratory Standards Institute
CrI	Credible interval
EFSA	European Food Safety Authority
EL	Eliana Lima
EMA	European Medicines Agency
ESBL	Extended spectrum beta-lactamase
EU	European Union
EUCAST	European Committee on Antimicrobial Susceptibility Testing
FL	Fiona Lovatt
JK	Jasmeet Kaler
LIWC	Linguistic Inquiry and Word Count
MAE	Mean absolute error
MRSA	Methicillin resistant *Staphylococcus aureus*
NHS	National Health Service
NLP	Natural language processing
NWT	Non-wild type
PCU	Population correction unit
RB	Rob Burgess
RUMA	Responsible Use of Medicines in Agriculture
TBP	Theory of Planned Behaviour
UK	United Kingdom

UK-VARRS	United Kingdom Veterinary Antimicrobial Resistance and Sales Surveillance
VIF	Variance inflation factor
VMD	Veterinary Medicines Directorate
WT	Wild type

Outputs arising from the thesis

Peer reviewed publications

Doidge, C., Lima, E., Lovatt, F., Hudson, C., & Kaler, J. (2021). From the other perspective: Behavioural factors associated with UK sheep farmers' attitudes towards antibiotic use and antibiotic resistance. Plos one, 16(5), e0251439. doi: 10.1371/journal.pone.0251439

Doidge, C., West, H., & Kaler, J. (2021). Antimicrobial Resistance Patterns of Escherichia coli Isolated from Sheep and Beef Farms in England and Wales: A Comparison of Disk Diffusion Interpretation Methods. Antibiotics, 10(4), 453. doi: 10.3390/antibiotics10040453

Doidge, C., Ferguson, E., Lovatt, F., & Kaler, J. (2020). Understanding farmers' naturalistic decision-making around prophylactic AMU in lambs using a grounded theory and natural language processing approach. Preventive Veterinary Medicine, 105226. doi: 10.1016/j.prevetmed.2020.105226

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1. General Introduction

Antimicrobials are chemicals that can limit the growth of, or kill, microorganisms including bacteria, viruses, protozoa and fungi[1]. Bacteria have evolved to produce antimicrobials as metabolites in order to survive in competitive environments (Hibbing et al., 2010). Most of the antimicrobials that humans use today to treat bacterial diseases are derived from these natural products. Antimicrobial resistance (AMR) has emerged in parallel with the discovery and use of new antimicrobial compounds to control infection in humans and animals (Aslam et al., 2018). Bacteria were able to respond to the use of antimicrobials through the evolution of resistance mechanisms. Some notable resistance mechanisms include the production of β-lactamases, which confer resistance to β-lactam antimicrobials such as penicillins, and drug efflux pumps, which prevent the accumulation of antimicrobial compounds in the bacteria (Alekshun and Levy, 2007). Rates of discovery of new compounds have diminished since the 1960's, and so synthetic analogues of natural products were produced in response to the emergence of AMR (Brown and Wright, 2016). However, it is now apparent that the rate of spread of AMR has overtaken the rate of drug discovery. Therefore, new ways to reduce the burden of AMR are required.

Several reports have identified a correlation in antimicrobial use (AMU) in humans with AMR (Costelloe et al., 2010, Yang et al., 2018) and a correlation between AMU and AMR in livestock species has also been identified (Chantziaras et al., 2014). A cross-national database study on AMU in Europe observed that the countries with high use had higher rates of resistance (Goossens et al., 2005). There is also evidence that a reduction in AMU can lead to a reduction in resistance. For example, with the reduction of veterinary AMU in Belgium, the AMR rates of *Escherichia coli* decreased for the majority of antimicrobials (Callens et al., 2018). It is now widely accepted that AMU leads to AMR. A meta-analysis of intervention studies demonstrated that a reduction in AMU in food-producing animals was associated with a reduction in resistance in both food-producing animals and humans (Tang et al., 2017). A whole genome-sequence analysis of human and animal isolates from a *Salmonella Typhimurium* DT104 outbreak indicated that transfer of AMR between species may be rare (Mather et al., 2013). It was shown that within-host transmission of the bacterium occurred most commonly, and there were separate sources of infection for humans and animals. There still remains debate over the extent to which AMU in food-producing animals can cause AMR in humans (Bennani et al., 2020). This may

[1] In this thesis the term antimicrobial is used to refer to antibacterial antimicrobials unless otherwise stated

be due to the complicated relationship between humans, food animals, and the environment, which makes it difficult to identify the origin of resistance.

Although associations between AMU in animals and AMR in humans have been found, Marshall and Levy (2011) highlight that there is very little direct evidence of the mechanisms of transfer of resistance from animals to humans. One of the reasons for this is because there is often an absence of records on the quantities of antimicrobials used on the farms. Indeed, a review of the effects of AMU in livestock on drug-resistant *Salmonella* in humans observed that there were few reports that included the use of antimicrobials on the farm – and no reports that linked AMU in agriculture with resistance in humans (Helke et al., 2017).

The increasing occurrence of multi-drug resistant bacteria coupled with the lack of discovery of new antimicrobials in recent decades means that those currently in use need to be preserved. As one of the suggested drivers of AMR is inappropriate use of antimicrobials, there has become increasing awareness for the need for surveillance of AMU, and mechanisms to reduce AMU are urgently required (World Health Organisation, 2015, O'Neill, 2016, UK Government, 2019). To uncover these mechanisms, studies into the human behaviour regarding AMU are necessary to understand which areas need to be targeted for change (UK Government, 2019). Yet, a systematic review of interventions to improve antimicrobial prescribing practices in hospitals found that behavioural and social influences are not often considered (Davey et al., 2017).

This review will begin with an overview of the surveillance of veterinary AMU and AMR in the United Kingdom (UK) and different countries, and AMU and AMR in livestock with a particular focus on sheep and beef. Then, the review will cover decision-making of farmers and farm veterinarians regarding AMU.

1.1. AMU and AMR surveillance and policy in the veterinary sector

1.1.1. UK AMU surveillance and data

Monitoring AMU is an important first step in the prevention of sub-optimal use of antimicrobials. However, in the veterinary sector this is difficult due to a lack of surveillance data to act as a benchmark (Van Boeckel et al., 2015). Currently in the UK, veterinary AMU estimates are derived from pharmaceutical sales data (VMD, 2020b). The metrics based on antimicrobial sales are calculated using a Population Correction Unit (PCU) as the denominator, which is the standard weight of animals at treatment time multiplied by total number of animals in the population. The tonnage of antimicrobials sold is then divided by the PCU to get mg/PCU. The data is published annually by the Veterinary Medicines Directorate (VMD), and the most recent publication reports that there has been a reduction in the sales of veterinary antimicrobials, from 62.5 mg/PCU in 2014, to 29.5 mg/PCU in

2018 (VMD, 2020b). There was a slight increase to 31.0 mg/PCU in 2019. The reduction in antimicrobial sales was mainly due to a large reduction in antimicrobials with indication for use in pigs and poultry.

The reporting of antimicrobial sales data does not include AMU by species or production class and can only be taken as an approximation. This is because many antimicrobial products are licensed for more than one species. Additionally, sales data does not consider the dose rate of the drug, and so on-farm consumption data would provide more useful information for AMU comparisons. The VMD report published in 2017 was the first to include usage data from meat poultry, egg, pig, and dairy sectors (VMD, 2017). It also highlighted the need for collection of usage data in the beef and sheep sectors. In the report published in 2020, usage data from a sample of beef farms covering 9.6% of slaughter animals in Great Britain (GB) were included (VMD, 2020b). At present, sheep farm consumption data is still not included in the report.

In 2016, the British government set a target to reduce AMU in livestock species to 50 mg/PCU by 2018 (HM Government, 2016). This target was already met by 2016, and so the government set at new target to reduce AMU by 25% between 2016 and 2020 (UK Government, 2019). Additionally, individual sector-specific voluntary targets were introduced by the Responsible Use of Medicines in Agriculture alliance (RUMA) in 2017 (RUMA, 2017). RUMA is a group of organisations that represent all stages of the food chain and aims to champion the responsible use of animal medicines in UK livestock. An initial beef sector target for antimicrobial reduction in mg/PCU was not obtainable due to a lack of data on current usage. The sheep sector was aiming for a 10% reduction in AMU, which would represent a usage target of below 10 mg/PCU, but this was based on the limited data available. This illustrated that there was a need to start collecting usage data on sheep and beef farms in the UK to allow for accurate benchmarking in these sectors.

RUMA has released a report every year since 2017 to keep track of progress of the AMU targets. In 2020, new RUMA targets were released in line with the new 5-year action plan to tackle AMR released by the UK government in 2019 (UK Government, 2019, RUMA, 2020). The latest report now includes a usage figure for beef consumption (RUMA, 2020), which is the same as what is published in the annual VMD report. The sheep consumption data now includes small sets of data from multiple sources. Therefore, trends in the data are unable to be determined at present. Hence, the latest report took a new stance on targets for the sheep and beef sectors. New targets were set to capture usage data from 10% of sheep and beef farms by 2024 and were also focussed on improving herd and flock health plans (RUMA, 2020).

1.1.2. AMU surveillance in other countries

There are very few countries that collect veterinary antimicrobial prescription data at a nationwide level; however, one of which is The Netherlands (Speksnijder et al., 2015a). Here, prescription and usage data is collected from individual farms and veterinarians. This allows them to set species-specific targets against a benchmark. Those that exceed this benchmark may face disciplinary actions (e.g. a fine). This may act an incentive for AMU reduction.

Another country that collects detailed antimicrobial consumption data is Denmark. AMU has been monitored in Denmark since 1995 (DANMAP, 2016). Approximately 84% of production animals in Denmark are pigs, and despite an increase of swine production by 47% between 1992 and 2008, AMU declined by 51% (Cogliani et al., 2011). This is believed to be a result of the implementation of legislation: limiting the profits of veterinarians from medicine sales, promoting preventative strategies such as monthly veterinarian farm visits, and the introduction of the prescribing cascade (DANMAP, 2016). However, since the ban on antimicrobial growth promoters in 2000, the use of therapeutic antimicrobials was gradually increasing. To tackle this, the "Yellow Card Initiative" was instigated in 2010, where farmers would face legal interventions if their AMU was above a threshold (Lopes Antunes and Jensen, 2020). If farmers were still above the threshold after nine months of being issued a yellow card, they would require a reduction strategy from a second-opinion veterinarian and quarterly visits from the authority. Since the introduction of the Yellow Card Initiative, there has been a year on year reduction in AMU (Lopes Antunes and Jensen, 2020).

On a more international level, the European Surveillance of Veterinary Antimicrobial Consumption (ESVAC) report currently includes the sales of veterinary antimicrobial agents from thirty-one European countries (EMA, 2020). From 2011 to 2018, there was a decrease of 34.6% in antimicrobial sales (in mg/PCU) for the twenty-five countries who have reported data each year. The UK had the fifth-lowest sales of antimicrobials (EMA, 2020). The most common antimicrobials sold were tetracyclines and penicillins, which is in line with the UK sales data (VMD, 2020b). However, the authors of the ESVAC report state that data from the report should not be used to compare countries, as more detailed information and analysis would be required (EMA, 2020).

1.1.3. AMR surveillance in the UK

Clinical surveillance of veterinary AMR in the UK is reported each year in the UK Veterinary Antimicrobial Resistance and Sales Surveillance (UK-VARSS) report (VMD, 2020b). This describes resistance levels to multiple respiratory, mastitis and zoonotic pathogens for cattle, sheep, poultry, and pigs. The results of the susceptibility testing for *E. coli* are also reported by age category (neonatal, pre-weaning and adult animals) and results for *Salmonella* species

are reported by serovars. Sheep and cattle specific AMR from the UK-VARSS report are described later in section 1.2 of this chapter. However, it is important to note that the clinical surveillance only evaluates bacteria from clinical samples submitted by veterinarians to government laboratories. This is therefore a biased population and care must be taken when interpreting the results as it is not known how representative the data is.

The UK-VARSS report also reports surveillance of healthy pigs and poultry on alternate years. For poultry, antimicrobial susceptibility testing was carried out for *E. coli, Salmonella* species and *Campylobacter jejuni*. Samples were collected at slaughter, on retail meat, from boot swabs and dust samples (VMD, 2019). For pigs, antimicrobial susceptibility testing from *E. coli* isolates obtained from healthy pigs at slaughter, and *Salmonella* isolates obtained from pig carcasses was reported (VMD, 2020b). This information is collected and reported as part of the European Union (EU) harmonised monitoring of AMR programme. The primary indicator for presenting AMR is the proportion of indicator *E. coli* isolates from broilers, fattening turkeys, fattening pigs, and calves that are fully susceptible to a panel of antimicrobials. However, the UK is exempt from monitoring isolates from calves as it does not meet the calf slaughter throughput criteria (VMD, 2020a). As pig and poultry data are collected on alternate years, the indicator is based on two calendar years. The proportion of fully susceptible *E. coli* isolates has increased by 83% between 2014/15 and 2018/19 (VMD, 2020b). Surveillance of healthy sheep and cattle in the UK has not been carried out by the UK government as it was not mandated by the EU.

The clinical isolates and the isolates from the EU surveillance reported in the UK-VARSS report are tested using different antimicrobial susceptibility techniques. The isolates from the EU surveillance were subject to testing using a standardised broth microdilution method, which use minimum inhibitory concentrations to determine AMR (VMD, 2020b). The breakpoints used to assess the susceptibility of isolates were set by European Committee on Antimicrobial Susceptibility Testing (EUCAST) (EUCAST, 2020a). Both clinical breakpoints and epidemiological cut-off values were used to assess susceptibility. Any Extended Spectrum β-lactamase (ESBL)- or AmpC-producing *E. coli* also underwent whole genome sequencing to detect AMR determinants. The clinical isolates were subject to antimicrobial susceptibility testing using the disk diffusion method using British Society for Antimicrobial Chemotherapy (BSAC) guidelines (Andrews, 2001). Interpretation was based on BSAC human clinical breakpoints where possible, otherwise Animal and Plant Health Agency (APHA) breakpoints were used (VMD, 2020a).

There are some problems with the current antimicrobial susceptibility testing methods. First, the breakpoints used were determined for antimicrobial susceptibility testing of human isolates and were not livestock-specific. These

human breakpoints may not represent susceptibility or resistance in bacteria isolated from livestock because of different responses to antimicrobials. Second, the calculations for the APHA breakpoints are not transparent. Finally, the antimicrobial susceptibility testing results cannot be compared because of inter-laboratory variation (Timofte et al., 2020). Thus, there is a need to develop livestock-specific breakpoints which are transparent and allow for comparisons between laboratories.

1.1.4. AMR surveillance in other countries

A few countries across the world have their own AMR surveillance systems for food-producing animals. Demark reports AMR in zoonotic bacteria and indicator *E. coli* and *Enterococcus* within the same report as its antimicrobial consumption (Høg et al., 2017). The Canadian Integrated Program for AMR Surveillance (CIPARS) monitors trends in AMR for chicken, pigs and cattle in Canada (Ebrahim et al., 2016). Others include Finland, France, Norway, Italy, the Netherlands, USA and Sweden (World Health Organisation, 2014). Still, the Wold Health Organisation remarked that differences in production systems, methodologies and bacterial isolates used means that comparisons between countries is difficult (World Health Organisation, 2014).

On a continental level, the European Food Safety Authority (EFSA) and European Centre for Disease Prevention and Control (ECDC) analysed data submitted by twenty eight EU member states (EFSA and ECDC, 2019). The report gave details on AMR in *Salmonella, Campylobacter*, *E. coli*, and methicillin-resistant *Staphylococcus aureus* (MRSA) isolates from humans, fattening pigs and calves less than a year old. Results showed that resistance to third-generation cephalosporins was uncommon in *Salmonella* and *E. coli* isolates obtained from calves and fattening pigs. However, data is still inconsistent as not all countries participate in all sampling methods which makes comparisons difficult.

1.2. AMU and AMR in the sheep and beef livestock sectors

1.2.1. Types of AMU in livestock

The use of antimicrobials in farming is essential for livestock health. Many of the endemic diseases of livestock animals are caused by bacterial organisms which may be responsive to treatment with antimicrobials. In addition to their therapeutic use, antimicrobials are also used as preventative medicines and as growth promoters. Feeding broad-spectrum antimicrobials to livestock has been shown to increase the size of an animal and meat produced (Dibner and Richards, 2005), and had been used in the USA and Europe for growth promotion since the 1950's. Antimicrobial growth promoters are fed at low concentrations, which creates an ideal environment for the selection of AMR genes. Antimicrobials have not been used as growth promoters within the EU since this practice was banned in 2006 (Regulation 1831/2003/EC).

Prophylactic and metaphylactic use of antimicrobials can aid in the prevention and control of livestock diseases. These are usually given at higher concentrations than antimicrobial growth promoters. A metaphylactic is used to treat a whole group of at risk animals when a clinical disease is found to be present within that herd or flock. For example, if a ewe suffers from a chlamydial abortion, the rest of the flock may receive antimicrobials to limit further abortions. A prophylactic is used before any signs of clinical disease, to prevent a disease from occurring in an at-risk population. Neonatal lambs are often given oral antimicrobials at birth to prevent diseases, for example (Lima et al., 2019). The prophylactic use of antimicrobials has been deemed a 'grey area' for policy makers, as it is difficult to distinguish what is appropriate or non-appropriate use (Morris et al., 2016).

Antimicrobials have been categorised in various ways by different organisations. The World Health Organisation splits antimicrobials into three categories depending on their importance to human health: critically important, highly important, and important (World Health Organisation, 2018). Critically important antimicrobials (CIAs) are further categorised into high-priority CIAs and highest-priority CIAs. The European Medicines Agency (EMA) has also categorised antimicrobials for use in animals to aid veterinary decision-making. These categories are A "Avoid", B "Restrict", C "Caution", and D "Prudence" (EMA, 2019). Category D reflects antimicrobials which should be used as first line treatments; for example, tetracyclines. Highest-priority CIAs, such as third- and fourth-generation cephalosporins, colistin, and fluoroquinolones are in category B and should only be used when there are no alternatives in categories C or D. No category A antimicrobials are authorised for use in food-producing animals.

In addition, the EMA has a hierarchy of preference for the route of administration of antimicrobials for animal use (EMA, 2019). Local individual treatments, using eye drops or intramammary preparations, for example, are considered the preferred option. Individual parenteral treatments are favoured over oral treatment. This is because it is difficult to give the correct doses with oral treatments via feed or drinking water. Furthermore, oral antimicrobial treatments have been shown to select for AMR at a greater rate (Zhang et al., 2013, Chantziaras et al., 2017). Group medications are considered to have a greater impact on AMR and therefore the EMA recommend that these should only be used when appropriately justified (EMA, 2019).

1.2.2. Antimicrobial prescribing regulations in the UK

In the UK, antimicrobials are a prescription-only medicine. Antimicrobials for animal use must be prescribed by a veterinarian, who needs to first carry out a clinical assessment of the animal. A clinical assessment is not defined by Veterinary Medicines Regulations and could be interpreted as an assessment

of relevant clinical information (RCVS, 2021). The animals must either be immediately seen before prescription, or recently enough for the veterinarian to have personal knowledge about the condition or health status of the animal (RCVS, 2021). The term "recently enough" is not defined by Veterinary Medicines Regulations or the Royal College of Veterinary Surgeons (RCVS) and is up to the veterinarians' professional judgement. It is therefore possible for farmers to obtain prescriptions from their veterinarian without an immediate physical examination of the animals in question.

Antimicrobials prescribed by veterinarians should be authorised for the country the veterinarian is practising in and the species the antimicrobial is to be used in. Antimicrobials may be authorised for use in the UK, GB (only England, Wales, and Scotland) or Northern Ireland only (RCVS, 2021). If no such medicine is available then veterinarians may prescribe in accordance with the Cascade. The Cascade is a list of options for prescribing antimicrobials that are not authorised for use in the intended animal. This list is in order of preference. For example, if there is no antimicrobial authorised in GB or UK-wide for a condition affecting the intended species, the preferred choice is to use an antimicrobial that is authorised for use only in Northern Ireland. The option of last resort is a human medicine imported from outside of the UK.

Veterinarians must prescribe antimicrobials responsibly to minimise resistance development and be accountable for their prescribing choices (RCVS, 2021). RUMA defines responsible use as using as little antimicrobials as possible but as much as necessary (RUMA, 2019c). For example, antimicrobial prophylaxis should only be used in rare circumstances on the basis of the veterinarians' epidemiological and clinical knowledge and should not be used as routine.

1.2.3. AMU and resistance in the UK sheep and beef industry

There are over 72,000 breeding ewe holdings (AHDB, 2018b), and 59,000 beef cow holdings in the UK (AHDB, 2018a). The sheep sector is the largest livestock sector in the UK and accounts for 40% of the overall livestock PCU (VMD, 2020a). Here, there is a stratified sheep system, which utilises the land available, and consists of hill, upland, and lowland farms (NSA and NFU, 2014). Beef cattle production is broadly categorised into suckler, rearing, and finishing units, with many units combining multiple categories. AMU may vary between different production types due to the particular challenges they face (Davies et al., 2017). For example, the hardiness of breeds differs in sheep production systems, and age of the population differs in beef systems.

The sheep and beef industries are highly interlinked, and the two livestock species often co-exist on farm holdings. For antimicrobial sales data, this makes it particularly difficult to interpret use between the species when multi-species drugs are used. Furthermore, there are significantly fewer

antimicrobials that are specifically licenced for use in sheep, suggesting that that there may be a need for the use of unauthorised products prescribed 'under the Cascade'. As of yet, there are no comprehensive data to determine the antimicrobial consumption on sheep and beef farms, and unlike pig and poultry sectors, there is currently no way to centrally collate on-farm AMU data. This is because there are a large number of small farms and the supply chain is more fragmented compared with pig and poultry sectors (RUMA, 2020). Additionally, there are fewer specialist sheep and cattle veterinarians compared with pigs and poultry, and sheep and beef farmers usually have very few veterinary visits to their farm (Kaler and Green, 2013).

A programme currently being developed by AHDB and the Department for Environment, Food and Rural Affairs (DEFRA) promises more effective data collection of livestock data in the future (AHDB, 2020a). This could be used as a central system for collating AMU data from sheep and beef farms. Little is known about sheep and beef farmers antimicrobial recording practices, and research into this may be beneficial for the role out of the new data collection service.

Respiratory disease, calf diarrhoea, calf navel ill, mycoplasma, lameness, calving problems, and caesareans were described by RUMA experts as the top reasons for AMU in the beef sector (RUMA, 2017). It was also highlighted that youngstock were a high risk category for AMU. In the sheep sector, the main areas for AMU are to control lameness, to control abortion, and whole flock treatments in lambs to control neonatal disease.

From an analysis of 207 commercial British sheep flocks, the mean average AMU was estimated at 11.38 mg/PCU (Davies et al., 2017). However, flock treatment levels ranged from 0 to 116.9 mg/PCU, indicating that appropriate usage may not always be followed. These usage figures were obtained from sales records from eight veterinary practices. The small number of practices means that this data was not representative of all flocks in the UK, as the prescriptions may be affected by individual practice prescribing styles. Indeed, 21% of the variation in AMU could be attributed to the veterinary practice. The study also only took into account sheep-only farms. A study of commercial sheep farmers in the UK found that 78% of those investigated also had an enterprise other than sheep (Lima et al., 2018). Thus, the previous attempt to quantify AMU in sheep flocks in the UK excluded a large proportion of the sheep farming population.

The latest RUMA report provided AMU estimates for sheep farms from seven data sources. The mean use from these sources ranged from 2.26 mg/kg to 20.43 mg/kg, revealing that there are large differences between veterinary practices and industry groups (RUMA, 2020). All data sources did, however, show that the use of highest-priority CIAs was very low (<0.005 mg/kg).

There is little published data on antimicrobial use on beef farms in the UK. The data reported in the UK-VARSS report from 4,188 farms in GB showed that AMU was estimated at 24.4 mg/kg (VMD, 2020b). These results were surprising as AMU on beef farms was expected to be lower than on dairy farms, but the report suggests that this was not the case. The result was subject to scepticism as the methodology of the analysis was not transparent. Like the sheep sector data, farms that also had a sheep enterprise were excluded from the analysis. A recent analysis of Scottish dairy and beef farms had findings that opposed those reported in the UK-VARSS reports, where beef farms had lower AMU than dairy farms (Humphry et al., 2021). This study used sales data and did not account for sheep that may have been present on farms. As of yet, there has been no published data on the quantities of AMU on mixed-species sheep and beef farms. The scarce AMU data for the sheep and beef sectors and the large variation in use reported for sheep indicate that further in-depth research is required to compare with these results.

There is also a paucity of information on the rates of AMR on sheep and beef farms in the UK. The UK-VARSS report does not distinguish between the antimicrobial susceptibility results of beef and dairy cattle. However, cefotaxime resistant *E. coli* was isolated from 11.7% of cattle samples from England and Wales in 2019 (VMD, 2020b). Cefotaxime is not used in sheep and beef cattle because it is a third-generation cephalosporin and therefore a category B antimicrobial. Cefotaxime resistance in *E. coli* samples from beef calves that have no previous exposure to cefotaxime has been previously reported, and is linked to the possession of ESBL genes (Mir et al., 2016). Resistance in *E. coli* appears to decline with age of the animal, and therefore may be as a result of treatment with other antimicrobials for neonatal diseases. Alternatively, it has been found that beef calves can carry cefotaxime resistant bacteria without exposure to any antimicrobials at all – and this suggests that resistance genes may be acquired from the environment (Mir et al., 2018).

Previous research has focussed on investigations into presence of ESBL-producing enterobacteriaceae in beef cattle. ESBLs have been identified in *E. coli* isolated from the faeces of British beef cattle (Snow et al., 2011), including from apparently healthy animals (Velasova et al., 2019). Bringing in new animals, changes in feeding two weeks before sampling, and dairy herds with beef cattle were significant factors for increasing the odds of resistance to cephalosporin (Velasova et al., 2019). A comparison of indoor dairy cows and outdoor beef cattle identified a higher presence of resistance in *E. coli* isolated from the indoor cattle (Bok et al., 2015). Therefore, the combined cattle resistance data reported in the UK-VARSS should be interpreted for beef cattle with caution due to the inclusion of data from the dairy industry.

To the author's knowledge, the most recent study of AMR in *E. coli* isolated from UK sheep farms was published in 2008, and was based on samples collected in 1999 (Enne et al., 2008). In this sample, only 3% of 836 isolates from sheep were resistant to at least one of the antimicrobials tested. A larger proportion of sheep were found to carry antimicrobial resistant *E. coli* in Switzerland, where ESBL producing *E. coli* were isolated from 8.6% of faecal samples (Geser et al., 2012). It would be beneficial to collect more up-to-date resistance data for *E. coli* from healthy sheep in the UK.

1.3. Antimicrobial decision-making

For successful policy implementation to reduce the use of antimicrobials, further understanding is required into the decision-making processes when prescribing and using antimicrobials. Various social science methods have been used to understand farmers' and veterinarians' decision-making around AMU. Qualitative methods such as semi-structured interviews have been used to understand veterinarians' prescribing decisions on antimicrobial dry cow therapy (Higgins et al., 2017), and understand the social influences on antimicrobial treatment in dairy cows (Swinkels et al., 2015). Researchers have also collected qualitative data from both farmers and veterinarians and analysed the results simultaneously to be able to compare and contrast the findings from the two groups (Coyne et al., 2014, Golding et al., 2019). Others have used survey methods to compare groups of farmers and veterinarians from different countries (Postma et al., 2016, Visschers et al., 2016a) and from different sectors (De Briyne et al., 2013). This section presents some of the main findings in previous antimicrobial decision-making research.

1.3.1. Veterinarian decision-making

Studies from pig, poultry and dairy sectors found that veterinarians were the most influential source for farmers' AMU (Jones et al., 2015, McDougall et al., 2017, Etienne et al., 2017). In sheep farms, 21% of the variation in AMU could be attributed to the veterinary practice, which highlights that veterinarian prescribing behaviour influences the overall AMU on farm (Davies et al., 2017). In the UK, all antimicrobials for veterinary use must be prescribed by a veterinarian. It is therefore important to identify what motivates veterinarians to prescribe antimicrobials. In this section, a summary of the previous evidence around the influences of farm animal veterinarian prescribing behaviour is described.

1.3.1.1. Experience and knowledge

One of the major factors that influenced prescribing behaviour was the veterinarians' previous experience with the disease and therapy (De Briyne et al., 2013, Speksnijder et al., 2015a, McDougall et al., 2017, Coyne et al., 2018). Veterinarians may be more likely to prescribe antimicrobials if they were uncertain about the diagnosis (Golding et al., 2019). Personal experience was an important factor when choosing an antimicrobial (Gibbons et al., 2013).

When veterinarians were more experienced, they were more confident in their prescribing decisions (Speksnijder et al., 2015b). Whereas, newer graduates tended to be less confident in their own abilities and level of knowledge (Higgins et al., 2017). Both under-confidence and over-confidence in their prescribing decisions can lead to sub-optimal AMU (Higgins et al., 2017).

1.3.1.2. Farm, disease and drug factors

Research suggests that on-farm factors can influence differences in veterinarian prescribing behaviour. Veterinarians thought that prescribing decisions varied depending on the type of farm and production system (Golding et al., 2019). For example, the infrastructure of the farm may cause specific problems requiring AMU (Pucken et al., 2019). Similarly, management practices such as the way livestock were housed and bedded, may contribute to AMU (Coyne et al., 2014).

The clinical presentation of disease was a major influence of prescribing decisions for pig veterinarians (Coyne et al., 2018). For dairy veterinarians in New Zealand, prescribing was chiefly based on diagnosis (McDougall et al., 2017). Issues related to the ease of administration for the farmer and route of administration influenced Irish cattle veterinarians choice of antimicrobials (Gibbons et al., 2013).

1.3.1.3. Diagnostic tests

Although diagnostic tests were perceived to be useful by veterinarians, they have been widely reported as not often used (De Briyne et al., 2013, Speksnijder et al., 2015a, McDougall et al., 2017, Coyne et al., 2018, Golding et al., 2019, Chan et al., 2020). One of the main reasons for the lack of uptake in diagnostic testing was the costs involved (De Briyne et al., 2013, Norris et al., 2019). Farm animal veterinarians in the UK did not consider diagnostic tests as necessary for common diseases (Chan et al., 2020). Additionally, the time taken for diagnostic testing was a barrier towards their use, and veterinarians were more likely to consider diagnostic testing if they could be provided with rapid results (De Briyne et al., 2013, Golding et al., 2019, Norris et al., 2019). Research also suggests that testing is more frequent for certain species and varies between countries (De Briyne et al., 2013, Bourély et al., 2018). For example, British dairy veterinarians used rapid diagnostic tests more often than pig or poultry veterinarians (Buller et al., 2020).

1.3.1.4. Economic considerations

Economic considerations was a significant factor in veterinarians' prescribing patterns (Coyne et al., 2014). For example, the perceived willingness of the farmer to invest in disease prevention strategies such as vaccination has shown to be an influencing factor for veterinarians (Speksnijder et al., 2015a). Veterinarians in the Netherlands also thought that farmers used antimicrobials in their animals instead of preventative measures, and that use

of antimicrobials was economically beneficial to treat clinical symptoms (Postma et al., 2016). Cost can contribute to bad antimicrobial prescribing practices; for example, prescribing CIAs because of their shorter withdrawal periods (Golding et al., 2019). Pig veterinarians feared that a reduction in the use of antimicrobials may increase the price of meat, resulting in supermarkets buying cheaper meat from abroad where antimicrobial regulations are more relaxed (Coyne et al., 2016).

1.3.1.5. Relationship with farmer

The relationship with the farmer is particularly important in veterinarians' decisions to prescribe antimicrobials. A prominent driver for pig veterinarian prescribing behaviour was pressure from clients (Coyne et al., 2016). To remain in business, veterinarians believed they must keep their clients satisfied, even if this meant prescribing antimicrobials at request when they did not think it was needed (Speksnijder et al., 2015a). In other words, a veterinarian may be influenced to prescribe an antimicrobial if the farmer wants or expects it (Gibbons et al., 2013).

To effectively communicate clinical cases with farmers, veterinarians felt that they needed to be trusted by their clients. Less experienced dairy veterinarians found it difficult to gain this trust and therefore found it challenging to promote antimicrobial stewardship practices (Higgins et al., 2017). Similarly, veterinarians were influenced by their level of trust in the farmers' abilities. For example, farm veterinarians were more likely to prescribe if they were confident that the farm staff would use antimicrobials responsibly (Coyne et al., 2018).

1.3.1.6. Risk perception and othering

Previous research suggests that farm veterinarians understood their responsibilities towards antimicrobial stewardship and were aware of the risks of AMR (Golding et al., 2019). However, veterinarians did not often consider their own antimicrobial prescribing as contributing to AMR. Veterinarians have noted that they rarely see cases of AMR themselves (Speksnijder et al., 2015a). They instead put the blame on other veterinarians, as well as AMU in other countries. For example, British pig veterinarians believed their AMU was much lower than in other countries (Coyne et al., 2016). Similarly, pig veterinarians were concerned that antimicrobial prescribing was less responsible in human medicine (Coyne et al., 2018). The concept in which veterinarians blame other societal groups for AMR and do not identify these behaviours within their own group is called "othering" (Coyne et al., 2018, Golding et al., 2019).

Although veterinarians were aware of the risks of AMR, they did not consider it as an immediate risk to them (Golding et al., 2019). Veterinarians perceived that the benefits of AMU outweigh the risks involved, and this varied depending on the country where veterinarians were practising (Visschers et

al., 2016a). Research by McDougall et al. (2017) indicated that perception of risk can also vary depending on the veterinarian characteristics, including gender, experience, and position in practice.

1.3.1.7. Policy and regulation

The policy and regulations relating to antimicrobial prescribing can have a large impact on veterinarian decision-making. Danish pig veterinarians prescribing decisions were largely influenced by the Yellow Card Initiative (Eriksen et al., 2019). Support for AMU policies has been shown to be dependent on existing policies within the veterinarians' respective countries (Postma et al., 2016). One of the barriers towards a reduction in AMU was veterinarians' concerns about the negative consequences to animal health and welfare (Speksnijder et al., 2015a, Coyne et al., 2016). Additionally, introducing new policy may have different effects on the decision-making of different veterinary sectors. For example, a new decree in France requiring an antibiogram before certain CIAs can be used had little effect on the prescribing behaviours of poultry veterinarians, but a drastic effect on bovine veterinarians (Bourély et al., 2018). Therefore, there may be cultural differences in prescribing behaviour between countries and also between veterinary sectors.

1.3.1.8. Summary of decision-making

Overall, a combination of social-psychological factors, such as perception of risk, experience and social relationships, and external factors, such as farm factors and regulations, may affect veterinarians' decision-making when prescribing antimicrobials to farmers. It is known that there may be cultural differences in prescribing behaviour between veterinary sectors. This previous research was mainly dedicated to veterinarian decision-making when prescribing to dairy and pig farmers. The findings from previous research could be used to inform studies into veterinary decision-making when prescribing to sheep and beef farmers, as this has not yet been investigated.

1.3.2. Farmer decision-making

Although antimicrobials are prescription-only medicines in the UK, most of the time it is the farmer who treats their animals. This is especially the case for sheep and beef farmers, who tend to have less veterinarian visits compared with other sectors (Lowe, 2009, Kaler and Green, 2013). Therefore, it is important to understand farmers' AMU decision-making. In this section, a summary of the previous evidence around the influences of farmer AMU behaviour is described.

1.3.2.1. Experience and knowledge

Farmers often use their own knowledge to make decisions on AMU. For example, experience was the highest ranking influence for antimicrobial choice for New Zealand dairy farmers (McDougall et al., 2017). Similarly, Tennessee cattle farmers often used their own knowledge and judgment

when deciding to use antimicrobials (Ekakoro et al., 2019). Being able to judge their animals' health by eye was important for dairy farmers (Fischer et al., 2019). Fischer et al. (2019) concluded that when farmers do not adhere to recommendations, this may be due to economic constraints rather than lack of knowledge around animal health. Conversely, Jones et al. (2015) showed that around half of UK dairy farmers studied were not aware of current AMU guidelines for the sector.

1.3.2.2. Social norms

Social norms have been shown to be influential in farmers' AMU decision-making. Social norms can be split into two different types: injunctive norms and descriptive norms (Cialdini et al., 1990). Injunctive norms represent perceptions of what others approve or disapprove of. Whereas, descriptive norms represent perceptions of whether other people carry out the selected behaviour.

Dairy farmers in the UK were influenced to reduce their AMU through the injunctive norm that society would approve of this behaviour (Jones et al., 2015). Vasquez et al. (2019) showed that for New York dairy farmers, family members, milk plants, and veterinarians were important injunctive norm attributes for the intention to use antimicrobials prudently. Injunctive norms may also play a role in influencing inappropriate AMU. For example, perceived social approval from other farmers and veterinarians led to extended treatment of mastitis in dairy farms (Swinkels et al., 2015). Extended antimicrobial treatment of mastitis was also a descriptive norm as dairy farmers believed that other (good) dairy farmers carried out this behaviour (Swinkels et al., 2015).

1.3.2.3. Role of the veterinarian

Although it has often been shown that veterinarians are one of the most influential sources of farmers AMU behaviour (Jones et al., 2015, Swinkels et al., 2015, McDougall et al., 2017, Fischer et al., 2019), this influence is not straightforward. Pig farmers in the UK believed that they had a mutual relationship with their veterinarian where prescribing decisions were discussed (Coyne et al., 2014). Farmers have also been shown to trust and have confidence in their veterinarians' AMU recommendations (Jones et al., 2015, Swinkels et al., 2015, Fischer et al., 2019).

Despite the apparent influence of the veterinarian, this may not play a role in motivating farmers to carry out antimicrobial stewardship. Farmers in the UK suggested that veterinarians were not part of their on-farm antimicrobial stewardship due to the costs of veterinary services (Golding et al., 2019). Similarly, Swiss dairy farmers did not believe that veterinarians were important influences for reducing AMU, with only a quarter of those studied willing to pay for farm-specific consulting by their veterinarian (Gerber et al., 2020).

1.3.2.4. Economic considerations

Farmers often cite economic considerations as one of the most important influences on their AMU. Economic constraints may lead to farmers not being able to carry out recommended AMU procedures (Fischer et al., 2019), or invest in infrastructure to help prevent diseases (Coyne et al., 2014). As mentioned in the previous section, the costs of veterinary services were seen as a barrier towards antimicrobial stewardship (Golding et al., 2019, Gerber et al., 2020). Farmers may use antimicrobials to ensure their animals stay healthy for sustainable economic gain (Ekakoro et al., 2019). On the other hand, the high costs of antimicrobials may influence farmers to reduce their usage (Coyne et al., 2019).

1.3.2.5. Industry and legislation

As well as other farmers and veterinarians, other outside actors have been shown to have an influence on farmers' antimicrobial decision-making. Farmers across pig, dairy, and veal calf sectors have been found to have negative attitudes towards antimicrobial regulators (Kramer et al., 2017). Pig farmers in countries with strict regulations such as Denmark and Sweden had lower intentions to reduce their AMU (Visschers et al., 2016a), although this may be due to a large reduction in AMU already. Farmers in the UK were worried about potential legislative changes that could restrict their AMU (Golding et al., 2019). In both the UK and Sweden, farmers felt that industry and consumer demand for cheap meat and dairy products was detrimental to antimicrobial stewardship (Fischer et al., 2019, Golding et al., 2019). Therefore, supermarkets and produce buyers played an important role in reducing AMU (Coyne et al., 2019).

1.3.2.6. Risk perception and othering

Although farmers appeared to be aware of the risks of AMU, they perceived these risks to be low (Golding et al., 2019). For example, farmers in the UK perceived the risks of AMR to be a future rather than current threat (Golding et al., 2019). Pig farmers tended to be more worried about financial and legal issues around AMU rather than AMR (Visschers et al., 2014, Visschers et al., 2015).

In a study carried out in the Netherlands comparing AMU attitudes of dairy, veal calf, and pig farmers, it was found that veal and pig farmers perceived AMR as a higher risk than dairy farmers (Kramer et al., 2017). This may be because pigs and veal cattle are likely to be more intensively managed than dairy cattle and therefore use more antimicrobials. However, perceiving AMR as a higher risk was inversely correlated with AMU (Visschers et al., 2016b, Kramer et al., 2017).

Previous research suggests that farmers often perceive their own AMU to be lower than other farmers (Visschers et al., 2014, Visschers et al., 2015). Farmers believed that they were using antimicrobials responsibly, and other

farmers were to blame for AMR (Coyne et al., 2014). Farmers also blamed AMU in human medicine for AMR (Golding et al., 2019). Therefore, like veterinarians, farmers engaged in othering.

1.3.2.7. Perceived benefits

Although there are risks involved with AMU, there are also many perceived benefits. For example, dairy farmers in France supported the systemic use of antimicrobials for the treatment of mastitis (Poizat et al., 2017). Farmers' gave reasons such as the blanket treatment is not expensive and is safer; whereas selective treatment would take too much time and was too complicated. Farmers may perceive that the benefits of using antimicrobial outweigh the risks. For example, pig farmers rated the benefits of antimicrobials, such as quick and easy administration and reducing animal deaths, much higher than the risks of antimicrobials (Visschers et al., 2016b).

1.3.2.8. Summary of decision-making

The antimicrobial decision-making of farmers is similar to that of veterinarians in that both of social-psychological factors and external factors may influence their decisions. Previous research also focusses heavily on pigs and dairy farmers. Yet, like veterinarians, cultural differences in farming sectors may exist. The previous research highlights a deficiency in knowledge around sheep and beef farmers' decision-making around AMU.

1.3.3. Lessons from human medicine decision-making

Whilst investigation into antimicrobial decision-making in veterinary medicine is still in its infancy, there is an abundance of literature available on decision-making in human medicine, including the decisions of nurses, doctors, dentists, and pharmacists (Lu et al., 2020). From the literature on human decision-making, there are many clear areas from which learnings can be applied to veterinary antimicrobial decision-making.

It is known that many social-psychological determinants influence the prescribing decisions of doctors. Some of these are similar to the influences of farmer and veterinarian decision-making. For example, like veterinarians worry about their relationship with farmers, doctors worry about their relationship with patients. Fear of losing patients was a commonly identified reason for prescribing antimicrobials (Teixeira Rodrigues et al., 2013), as well as a fear of being viewed as not technically capable by patients if they did not prescribe antimicrobials (Brookes-Howell et al., 2012). Perception of risk also influences doctors' decisions to prescribe antimicrobials. The decision to prescribe was weighted in favour of the immediate clinical risks, rather than the long-term risks of AMR (Broom et al., 2014). Doctors who perceived that antimicrobials were no risk to patients were more likely to prescribe compared to those that thought antimicrobials may be harmful (Klein et al., 2017).

There are also some determinants that have not been commonly investigated in veterinary decision-making, one of which is the role of habit. Habitual prescribing has been shown to override prescribing guidelines (Broom et al., 2014). Doctors become 'set in their ways' when they gain more experience, and tend to prescribe drugs that they are familiar with (Carthy et al., 2000). Doctors prescribe the same antimicrobial for the same condition routinely (Duane et al., 2016), and decisions may be made without any specific contemplation (Denig et al., 2002). There is little evidence that habit can influence veterinarians' decisions to prescribe antimicrobials to farmers. Findings that personal experience can influence veterinary prescribing decisions indicate that habit may be an important determinant and requires further investigation (Gibbons et al., 2013).

The cultural aspects relating to prescribing behaviours is very important in human medicine. In hospitals there appears to be the presence of a "prescribing etiquette" where cultural rules depict that doctors should not interfere with the prescribing of colleagues (Charani et al., 2013). Similarly, Broom et al. (2014) shows that decisions around antimicrobials were governed by what is considered appropriate within professional hierarchies. Whilst it is known that antimicrobial behaviours can vary by sector and country (Postma et al., 2016, Bourély et al., 2018), within veterinary medicine there has been little exploration of the importance of culture on decision-making (Swinkels et al., 2015). Most research has taken a psychological approach to understanding veterinary decision-making by focusing on influences that affect the individual. A sociological approach may help to understand the influences of sheep and beef farmers or veterinarians as a collective group (Broom et al., 2014).

As more evidence relating to the social-psychological determinants of doctors' antimicrobial decision-making has accumulated, attention has been drawn to how these can be used to bring about successful behaviour change. Many intervention studies have been unsuccessful and one of the reasons for this is that they fail to include social-psychological determinants (Charani et al., 2011, Donisi et al., 2019). It is suggested that intervention studies should adopt a theoretical approach and these should be informed by theory-driven research into the influences of AMU (Ness et al., 2016, Lorencatto et al., 2018, Talkhan et al., 2020). In human medicine, several studies have adopted a theoretical approach to understand prescribers' decision-making (Broom et al., 2014, Newlands et al., 2015, Klein et al., 2017, Ierano et al., 2019, Liu et al., 2019). However, in veterinary medicine, theory is rarely used to investigate farmers' and veterinarians' decision-making around AMU. Whilst some quantitative studies have based some of their survey items on theoretical constructs (Visschers et al., 2014), very few have used a theory throughout their study design. The Theory of Planned Behaviour has been

applied in two studies which investigated the antimicrobial decision-making of dairy farmers (Jones et al., 2015, Vasquez et al., 2019).

An inherent bias in asking human medicine prescribers, farmers, and veterinarians about their AMU and prescribing behaviours is social desirability, where respondents may be reluctant to disclose their true answers due to feelings of being judged. In the media, there has been scrutiny around the way antimicrobials are used by doctors, patients, and in farming (Morris et al., 2016, Collins et al., 2018), and antimicrobial stewardship has been actively encouraged by government and industry groups (O'Neill, 2016, UK Government, 2019, RUMA, 2020). Therefore, human medicine prescribers, farmers, and veterinarians may be sensitive to direct questioning of their antimicrobial behaviours. Some researchers have acknowledged social desirability bias as a limitation (Jones et al., 2015, Higham et al., 2018); however, in both human and veterinary medicine little has been done in study designs to reduce this bias.

1.4. Gaps in the research

This introduction highlighted a number of gaps in the research around AMU on sheep and beef farms in the UK. Firstly, there is a lack of data on AMU on sheep and beef farms in the UK, especially for mixed species farms. Accurate quantification of sheep and beef farms is reliant on data from on-farm medicine use records. Little is known about sheep and beef farmers antimicrobial recording practices, and research into this may be beneficial for the role out of the new data collection service.

Secondly, the UK government does not currently carry out active surveillance of AMR in sheep and beef cattle like it does with pigs and poultry. At the same time, there has been very little published research into AMR in healthy sheep and beef cattle in the UK. Sheep AMR data is out of date and beef data has focussed on ESBLs with little attention to other resistances. New data relating to a range of AMRs is needed. There is a need to develop livestock-specific breakpoints which are transparent and allow for comparisons between laboratories.

Although much is known about pig and dairy producers and veterinarians attitudes towards AMU and resistance, as of yet, there are few studies covering the sheep and beef sectors. Sheep and beef farmers and veterinarians may have different views on AMU and AMR compared with other farming sectors because of differences in the farming cultures. The review of decision-making literature identified that determinants commonly shown to influence human medicine prescribers, such as habit and cultural norms, were rarely described in veterinary literature. Furthermore, the review highlighted that there needs to be more focus on the study design of decision-making research to consider social desirability bias and the application of theory.

1.5. Aims of the thesis

The overall aim of the thesis is to examine how antimicrobials are used on sheep and beef farms in the UK. With considerations of the gaps in the research, there are four main objectives:

A) Evaluate AMU recording practices on sheep and beef farms using multiple data sources;

B) Identify patterns in AMR in sheep and beef farms in the UK;

C) Understand veterinary decision-making when prescribing antimicrobials to sheep and beef farmers;

D) Understand sheep and beef farmers' practices and perceptions around AMU.

1.5.1. Overview of chapters

To address the aims of the thesis, seven different studies were conducted. The overall structure of the thesis is presented in Figure 1 and the chapters of the thesis are summarised below

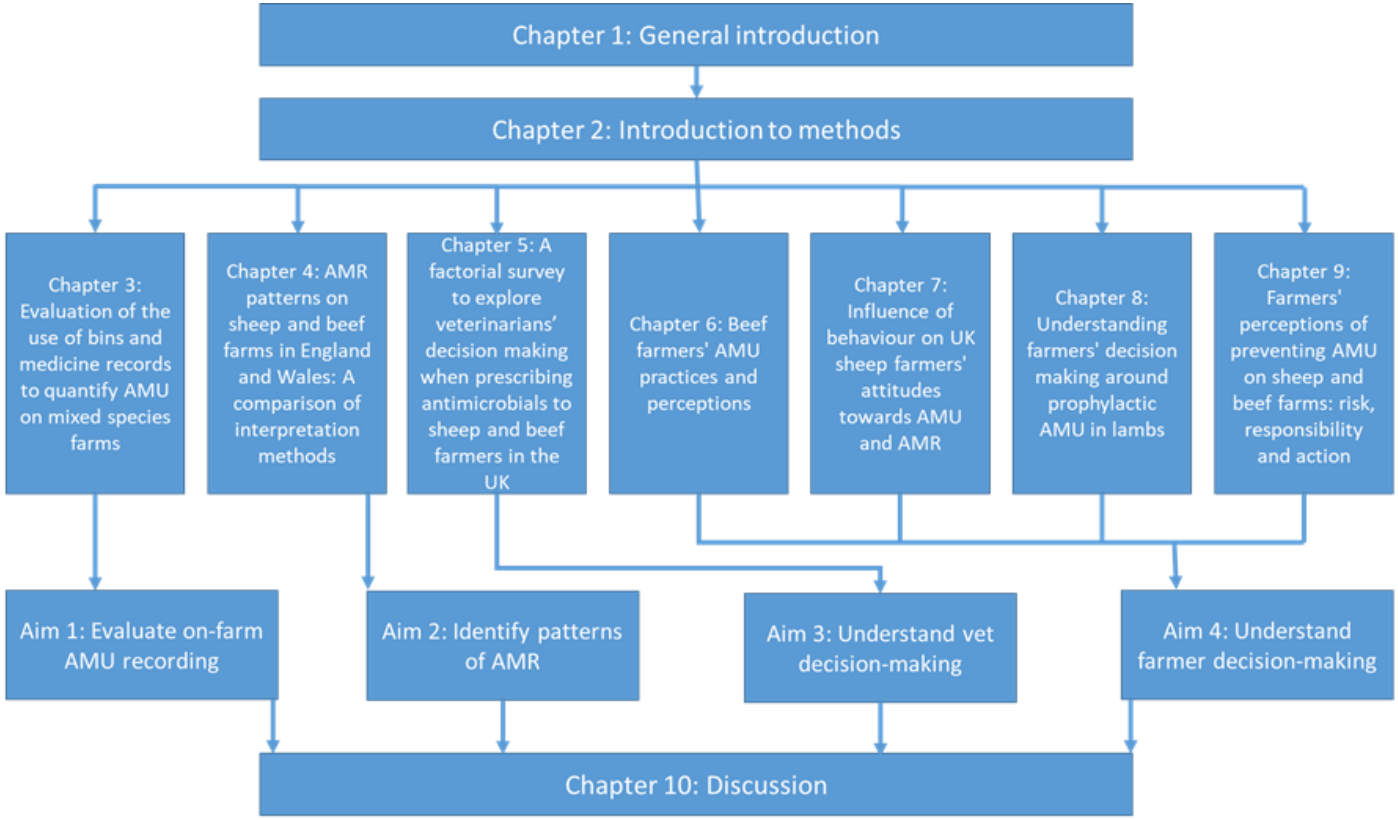


Figure 1: Diagram of the overview of the thesis structure and how chapters combine to investigate the thesis aims

Chapter 2: Introduction to methods

This chapter will introduce the methods used for the seven studies that make up this research project.

Chapter 3: Study 1 - Evaluation of the use of antimicrobial bins and medicine records to quantify AMU on sheep, beef, and mixed species farms

The AMU data from the medicine records of 35 sheep and beef farms in England and Wales was evaluated against antimicrobial bins.

Chapter 4: Study 2 - AMR patterns on sheep and beef farms in England and Wales: A comparison of interpretation methods

Antimicrobial susceptibility testing was carried out on presumptive *E. coli* isolated from faeces of sheep and beef cattle (N=1115) from 35 farms and methods of interpretation were compared.

Chapter 5: Study 3 - A factorial survey to explore veterinarians' decision-making when prescribing antimicrobials to sheep and beef farmers in the UK

A paper-based factorial survey was conducted to explore the factors that influenced UK sheep and beef cattle veterinarians' (N=306) decisions to prescribe antimicrobials to sheep and beef farmers.

Chapter 6: Study 4 - AMU practices and perceptions of beef farmers in England and Wales

A survey of farmers (N=171) in England and Wales who supplied beef to two abattoirs was conducted to understand farmers' AMU perceptions and the drivers for AMU for the treatment of pneumonia.

Chapter 7: Study 5 - From the other perspective: Behavioural factors associated with UK sheep farmers' attitudes towards AMU and AMR

A survey of farmers (N=461) in the UK who supplied lamb to two abattoirs was conducted to explore how their past farm practices were associated with their perceptions of AMU and AMR.

Chapter 8: Study 6 - Understanding farmers' decision-making around prophylactic AMU in lambs: Qualitative analysis and natural language processing of online discussion forums

Ten threads consisting of 431 posts from 133 different users were analysed qualitatively using a grounded theory approach and quantitatively using natural language processing to investigate farmers decision-making around prophylactic AMU in lambs.

Chapter 9: Study 7 - Farmers' perceptions of preventing AMR on sheep and beef farms: risk, responsibility and action

Qualitative, semi-structured interviews were conducted with sheep and beef cattle farmers from England and Wales (N=34) to explore risk perceptions around reducing AMU and AMR.

Chapter 10: General discussion

The final chapter brings together and discusses the findings from the seven studies. The research implications and conclusions arising from the results are discussed along with potential areas of future research.

2. Introduction to methods

The aims of this thesis require a multidisciplinary approach including epidemiology, social sciences, and microbiology. In this chapter, the methods used within each discipline are discussed. Seven studies form the research using methodologies from quantitative, qualitative and mixed methods research. First, methods for antimicrobial data collection are introduced in Section 2.1 and microbiological methods around antimicrobial susceptibility testing are described in Section 2.2. The social science methods are then introduced in Section 2.3, where quantitative methods, qualitative methods and mixed methods research are discussed. A brief overview of the methods used across the thesis are described in Section 2.4. A detailed account of the methods used in each study are described later within their individual chapters.

2.1. Evaluation of farmers' antimicrobial recording

From the general introduction, it was identified that on-farm medicine records are needed to quantify AMU on mixed-species farms. The aim of Study 1 within this thesis was to evaluate sheep and beef farmers' recording of AMU. To evaluate AMU from farmers' medicine records, an alternate method to collect AMU data is required to make comparisons. Common methods for the antimicrobial data collection are discussed below.

2.1.1. Data collection methods

Whilst many studies have aimed to quantify AMU on farms, there are relatively few that compare multiple methods of AMU data collection. Research into the quantification of on-farm AMU has been extensively examined the in dairy sector (Pol and Ruegg, 2007, Menéndez González et al., 2010, Saini et al., 2012, Stevens et al., 2016, Hyde et al., 2017, Nobrega et al., 2017, Redding et al., 2019, Antillón et al., 2020, Schrag et al., 2020) and the pig sector (Callens et al., 2012, Trauffler et al., 2014, Sjölund et al., 2015, Taverne et al., 2015, van Rennings et al., 2015, O'Neill et al., 2020). Fewer studies have quantified AMU of beef farms (Carson et al., 2008b, Brault et al., 2019, Hommerich et al., 2019, Diana et al., 2020, Hope et al., 2020) and sheep farms (Moon et al., 2011, Davies et al., 2017). Only a small number of these studies evaluated different methods of data collection (Carson et al., 2008b, Redding et al., 2014, Nobrega et al., 2017, Antillón et al., 2020, Pucken et al., 2021). Different methods for collecting information about the quantities of antimicrobials used at the farm level have been used with varying success and are described below.

2.1.1.1. Bin collection method

Multiple studies have used antimicrobial bins to collect AMU data on farms (Carson et al., 2008b, Saini et al., 2012, Redding et al., 2014, Stevens et al.,

2016, Nobrega et al., 2017). The bin collection method may be useful where farmers are not used to recording data. Farms are visited and labelled bins are placed around the farm near where medical treatments are given. Any empty medication used on the farm animals are placed in the bin. This can include empty medication bottles, tablet or powder containers, and intramammary tubes, for example. Broken bottles may be collected as well, or the label can be placed in the bin. Farms are then revisited after a period of time. In one previous study, the farmer was asked to give a score of reliability of the bin contents from 1-5 (Stevens et al., 2016). This gives an indication of how compliant the farmer is with depositing antimicrobial packaging. Product name, volume, and number of packages, herd identification number, and start and end date of collection period were recorded on a data sheet.

This method has the advantages that it is difficult to over-report AMU and performs well over long periods of time (Redding et al., 2014). Redding et al. (2014) found that the disadvantages of the bin collection method was that it did not perform as well as self-reporting over a short period of time for common drugs and intramammary tubes. This may be combatted by instructing the farmer that all medical treatments administered should be placed in the bin to avoid confusion about what is or is not an antimicrobial product (Stevens et al., 2016). However, bin collection may need to be more regular as farmers may not place used drugs in bins if they are already full.

The data obtained is not as detailed as from a record book, for example, useful information such as the indication for use is not known. Additionally, under-reporting may occur as some antimicrobial treatments have little packaging to dispose of, for example, intrauterine boluses (Carson et al., 2008b). Others have reported that the bin method was able to capture more AMU than other data sources (Nobrega et al., 2017, Antillón et al., 2020). Saini et al. (2012) recommended the use of the bin collection method as a producer-friendly and technician-friendly system to determine AMU, but acknowledged that an electronic recording system would promote better accuracy of recording treatments.

2.1.1.2. Farmer records

For many countries, including countries in the UK, farmers are required to record antimicrobials used in their animals (UK Government, 2013). This is especially important for mixed species farms, where veterinary sales records would not be able to distinguish which species the prescribed antimicrobial was used in. It should, therefore, be easy to gather data on on-farm AMU through collection of farmers' AMU records. However, the reality is that farmers do not accurately record AMU information. For example, important information is often missing from records (Trauffler et al., 2014, Pucken et al., 2021). Farm records usually give lower estimates for AMU compared with

other data collection methods (Menéndez González et al., 2010, Nobrega et al., 2017, Pucken et al., 2021).

Menéndez González et al. (2010) gave farmers the choice to record their AMU either by a paper journal, a spreadsheet, or an online herd management application. Comparisons of the three methods suggested that for better quality data, a list of commercial drug names and a more standardised way of recording dosage should be considered. When farmers had pre-defined categories, such as that used for the health events and age range, there was very little error. The paper journal recording was found to have more errors, especially when recording animal ID. This may be because the online and spreadsheet recording systems both have a drop-down list selection for animal identification, whereas the paper journal did not. These results show that there can be variation between types of recording methods farmers use, as well as variation between farmers' records and veterinarians' records.

2.1.1.3. Self-report surveys

Self-report surveys are commonly used to estimate on-farm AMU (Zwald et al., 2004, Pol and Ruegg, 2007, Redding et al., 2019, Hope et al., 2020). Self-report can produce recall bias, so to ensure this is minimised, the period of time the survey refers to should not be too long. For example, Zwald et al. (2004) used a period of 60 days to refer to antimicrobial practices. A disadvantage of this method is that it requires a lot of questions to obtain enough information, therefore the surveys are time-intensive, reducing response rates. Additionally, the information provided by farmers tends to be based on memory and estimates. However, because of the poor record keeping by some farmers, surveys based on recall may be more useful than using treatment records. For example, this method is more practical when attempting to obtain information about standardised group treatments, as these are well known to the farmer and may not be recorded (Callens et al., 2012). Conversely, the details of individual therapeutic treatments may not be remembered. Hope et al. (2020) suggested that self-report surveys might be useful for trends in AMU, but should not be used to rank or benchmark farms. Self-report surveys may also be used to capture information of the current management practices on the farm.

2.1.1.4. Veterinarian records

Some studies attempting to quantify AMU at the farm level used veterinary sales records (Trauffler et al., 2014, Davies et al., 2017, Hyde et al., 2017). The veterinary records take into account the amount of antimicrobials purchased rather than the amount of antimicrobials actually used on farm. When the online records of Austrian pig farmers were checked against their veterinarian dispensary records, 10% of farmers applied more - and 22% of farmers applied less than the veterinarian dispensed to them (Trauffler et al., 2014). Much like the farmer records, veterinarian records may be prone to errors

(Menéndez González et al., 2010). Sometimes farmers will use antimicrobials that were not prescribed by their veterinarian (Pucken et al., 2021). A further consideration is that a product purchased from the veterinarian in one year may be used on the farm in the following year.

2.1.1.5. Summary of data collection methods

Overall, bin collection, farmer records, self-report surveys, and veterinary dispensing records are common methods for collecting on-farm AMU data. Each method has its advantages and disadvantages which are summarised in Table 1.

Table 1: An overview of the common methods for collecting AMU on-farm

Data collection method	Advantages	Disadvantages
Bin collection	Good adherence by farmers	May forget to place some packaging into bin
	Performs well over long periods of time	Less detailed information
Farmer treatment records	Farmer should already be recording	Difficulties keeping track of group treatments
	Different formats can be used	Often incomplete information
Self-report survey	Performs well over short period of time	Subject to recall bias
	Useful for group treatment	Long survey required
Veterinary dispensing records	Useful to validate against on-farm data	Does not always reflect actual use by farmers

2.1.2. Quantification indicators

Once the usage data has been collected, it needs to be quantified using indicators to allow for comparisons between farms and identify trends in AMU. There are four types of AMU quantification indicators: weight-based, dose-based, course-based, and count-based. The indicator consists of a numerator and a denominator. The numerator expresses the amount of

AMU, and the denominator expresses the animal population at risk of being treated.

The most straightforward of the indicators is count-based. An example is the number of animals treated. A weight-based indicator reflects the mass of the active substance used. A problem with benchmarking using the weight-based metrics is that there is variation between dose rates for different medicines. In particular, CIAs have a lower course dose than non-CIAs (Mills et al., 2018). For example, ceftiofur, a third generation cephalosporin has a dose of 1.0 mg/kg, whereas oxytetracycline has a dose of 6.5 mg/kg. If benchmarking was carried out purely on this weight-based unit then this could push farmers to use CIAs to reduce their total (Brault et al., 2019). Therefore, to get around this problem a dose-based metric could be used.

The ADD (animal daily dose) is a dose-based metric defined as the average daily on-label dosage for the main indication multiplied by the approximate weight of an adult animal of the chosen species. A disadvantage of this metric is that no internationalised standard weights or doses have been defined (Jensen et al., 2004). For example the Netherlands use DDDA (defined daily dose animal), and Denmark report the DADD (defined animal daily dose) (Taverne et al., 2015). In previous studies, daily on-label dosage is based on their own countries compendium of veterinary products (Saini et al., 2012, Nobrega et al., 2017). Therefore, it may be difficult to compare usage with other countries.

In an attempt to harmonise data, the EMA have produced a standardised methodology for the assignment of defined daily dose for animals (DDDvet) and defined course dose for animals (DCDvet) (EMA, 2015). DDDvet is defined as the assumed average dose per kg animal per species per day. DCDvet is defined as the assumed average dose per kg animal per species per treatment course. The DDDvet is based on the mean standard dose of all veterinary medicine products of a particular active substance and administration route from nine countries in Europe. Additionally, the DDDvet metric uses fixed standard weights for animal species. However, this may cause problems when measuring at the herd or flock level as the standard weights or doses may vary from the DDDvet standards, and therefore will not accurately represent actual usage (Mills et al., 2018). Furthermore, using the mean dose rate for calculations may cause discrepancies between calculated use and actual use, as farms may tend to use the minimum or maximum dose rate instead.

It is important to consider the production system when choosing a denominator. The PCU – previously defined for use with antimicrobial sales data (see Section 1.1.1) - can also be used as a denominator for consumption data. However, because the PCU was originally designed to be used at a national level, PCU values have only been assigned for slaughtered beef cattle, and does not take into account live beef cattle. This means that in a

suckler herd, for example, where there will be live adult cows, the figure may not reflect the actual number of animals at risk of being treated. Additionally, the PCU unit does not account for time at risk. This may not be appropriate for comparisons of beef units as calculations typically consider usage over a year period. Although a suckler herd may have many cows present for the whole year period that the usage calculations consider, many cattle on a finisher unit will be present on a farm for less than a year. It is also important to consider the variation in population on sheep farms from pre-lambing to post-lambing. In these instances, it may be useful to use an animal-time denominator, such as animal-years. Animal-years is the total number of days on farm for each animal in each year divided by 365. In summary, there are two common denominators used for calculating AMU: the PCU which accounts for the variation in population size and weight of animals, and an animal-time denominator (e.g. cattle-years or 1000 animal days) which accounts for variation in population size and time at risk.

The adoption of different indicators can cause AMU benchmarking to alter, which is an important consideration when implementing policies. When Carson et al. (2008b) compared the units ADD/1000 animal days, and kg of active ingredient, they found that the ranking of the top five drugs used on the farms altered. Furthermore, previous studies have shown when farms are ranked using different denominators and numerators, the ranks of the farms changed (Mills et al., 2018), with the most variation occurring when the numerator was changed (O'Neill et al., 2018). Hyde et al. (2017) found that if only one metric was used, not all high using farms would be identified – as mg/PCU could poorly detect high intramammary AMU, and DDDvet/DCDvet could poorly detect high footbath AMU.

Some antimicrobial ingredients that may be used on farms are not available with the EMA DDDvet methodology, which means the DDDvet indicators might not be as reliable at the farm level (Diana et al., 2020). As a result, it may be best to adopt the EMA DDDvet or DCDvet when benchmarking at a national and international level, but when benchmarking at the herd level a separate indicator could be used which is more specific to the farm, for example a DDDuk or DDDfarm could be developed.

Collineau et al. (2017) also suggest that the choice of indicator should be dependent on the study objectives. Objectives include monitoring trends in AMU over time, comparing use between different species or countries, benchmarking farms, and studying the association between AMU and AMR (Collineau et al., 2017). These objectives need different indicators due to differences in the measurement requirements. For example, high resolution data are required when benchmarking farms, but not when comparing use between countries. In studies investigating the association between AMU and AMR, indicators need to take into account the level of exposure to

antimicrobials and use actual weights and used daily doses, rather than standardised values (Collineau et al., 2017).

In summary, the choice of AMU indicators is dependent on the objectives of the study, the dynamics of the study population, and the types of antimicrobials commonly used by the study population. An overview of the commonly used numerators and denominators that make up a treatment indicator are presented in Table 2. More than one indicator should be used when attempting to benchmark farms due to changes in ranking when different indicators are used.

Table 2: Summary of commonly used units that can make up a treatment indicator

	Unit
Numerator	Mg active ingredient
	Number of animals treated
	DDDvet
	DCDvet
Denominator	PCU
	Animal-time (e.g. 1000 animal days, cattle-years)

2.1.2.1. Measuring agreement between methods

Van Belle (2008) suggest that agreement should be assessed through addressing bias, scale differential, and precision (also known as concordance). Bland-Altman plots can be used to measure the agreement between two data collection methods. This is valuable to visually examine the bias and scale differential of data. To examine data further, it is useful to be able quantify the level of agreement between two methods through the use of parameters. Regression analysis and calculation of correlation coefficients is often used to understand the agreement between two methods (Redding et al., 2014, Nobrega et al., 2017). However, this will only show the strength and direction of the linear relationship between two measurements, rather than measuring the agreement (Bland and Altman, 2010). Two measurement can correlate perfectly and not be in agreement at all. It does not show differences due to bias (e.g. if one method measures consistently higher than the other) or scale (e.g. one method had greater variation in measurements than the other) (Van Belle, 2008). This might affect conclusions around the level of agreement between methods and the acceptability of using methods interchangeably.

2.2. Antimicrobial susceptibility testing

The literature review revealed a lack of information available on AMR in apparently healthy sheep and beef cattle in the UK. Therefore, Study 2 of the thesis aims to investigate AMR patterns on sheep and beef farms. To measure AMR on farms, antimicrobial susceptibility testing needs to be carried out. In this section, methods relating to on-farm sampling procedures, phenotypic AMR testing, choice of antimicrobials, and interpretation of results are described.

2.2.1. Sampling

As *Escherichia coli* is a commensal organism found in abundance in the intestinal tract of animals and humans, it is often used as an indicator organism for AMR within a population (Kaesbohrer et al., 2012). Researchers have implemented various sampling strategies for isolating *E. coli* and at present there appears to be no gold standard. As the organism is found in the intestinal tract, an easy way to obtain *E. coli* isolates is through sampling of faecal matter. *E. coli* isolates may be obtained from slurry (Ibrahim et al., 2016) or multiple faecal samples may be collected from the farm and pooled together (Akwar et al., 2008, Varga et al., 2009, Gibbons et al., 2013). Individual faecal samples may be taken from animals, for example by rectal swabbing either by the researcher (Carson et al., 2008a, Gibbons et al., 2013, Sjöström et al., 2020), or by the farmers themselves (Duse et al., 2015). Additionally, individual samples may be collected from the pen floor (Afema et al., 2019). Wagner et al. (2002) suggest that there was little difference between AMR patterns from faecal sample collected from the pen floor or directly from the rectum of cattle. Samples can also be collected from the carcasses of animals at the abattoir (Enne et al., 2008), however because abattoirs are usually high security, it may be difficult to gain access to this type of sampling. Other examples include boot swabs and dust samples (Schmid et al., 2013).

The sampling procedure is dependent on where the researcher wants to account for variation. Previous research indicated that individual samples and pooled samples could be used interchangeably as there was no significant difference in resistance estimates between the two methods (Bosman et al., 2012, Benedict et al., 2013) . However, when faecal samples are pooled, between-sample variation is lost. Studies have shown that most of the variance in AMR was attributed to the sample level (Bosman et al., 2012). Testing multiple isolates per animal was shown to give better estimate of herd prevalence of AMR compared with one isolate per animal (Villarroel et al., 2006). Additionally, Bosman et al. (2012) highlighted that testing multiple isolates from a single sample has an advantage in identifying resistance when resistance is rare. Therefore, it is beneficial to test more than one isolate per sample when the attribution of variance is unknown.

2.2.2. Phenotypic methods

The two main phenotypic methods to determine antimicrobial susceptibility are disk diffusion tests and dilution tests, such as broth microdilutions. For dilution tests, a series of tubes are set up with two-fold serial dilutions of the antimicrobial agent. The tubes are then inoculated with a standardised measure of microorganism suspension and incubated. The Minimum Inhibitory Concentration (MIC) is then recorded, which is the lowest concentration of antimicrobial agent that inhibits visible growth of a microorganism (McLain et al., 2016). For disk diffusion tests, an agar plate is inoculated with a standardised suspension of microorganism and then disks containing antimicrobial agents are placed onto the agar and incubated. Sensitivity to the antimicrobial is determined by the diameter of the inhibition zone.

An advantage of these phenotypic methods is that they are highly standardised (Pulido et al., 2013). The standardisation guidelines for disk diffusion and dilution tests are set by various organisations; two prominent ones are the Clinical and Laboratory Standards Institute (CLSI) and EUCAST. However, the methodologies and breakpoints set by the two organisations are not harmonised. The *E. coli* rates of resistance have been shown to be higher when using the EUCAST guidelines compared with the CLSI guidelines for multiple antimicrobial agents (O'Halloran et al., 2018, Cusack et al., 2019). Thus, the results would be reported significantly differently depending on which guidelines are adopted. The advantages of EUCAST guidelines over CLSI are that they are independent from the pharmaceutical industry and freely available from their website. Hence, EUCAST have been recommended as the guidelines and methodologies of choice for European researchers (Larrosa et al., 2019). The majority of countries within Europe have adopted the EUCAST guidelines as well as some countries outside of Europe, namely Australia and New Zealand (EUCAST, 2019). The disk diffusion test is recommended by EUCAST due to the versatility and availability of antimicrobial agents (Matuschek et al., 2014).

2.2.3. Choice of antimicrobial agents

It is important to test antimicrobial agents that are appropriate to the organism and the study aims (Reller et al., 2009). Studies investigating the antimicrobial susceptibility of *E. coli* isolates typically choose antimicrobial agents from a range of classes. Many antimicrobial agents that are used in veterinary medicine are not commonly used in human medicine, such as florfenicol and spectinomycin. This means that they usually do not have EUCAST breakpoints readily available. One alternative is to use antimicrobials with similar activities to the desired antimicrobial, for example, chloramphenicol instead of florfenicol (Reller et al., 2009).

2.2.4. Interpretation of inhibition zones

Clinical breakpoints are often used to determine clinically resistant bacteria. Clinical resistance can be defined as when treatment with antimicrobials is likely to have therapeutic failure. However, at present only human clinical breakpoints have been specified by EUCAST, and CLSI guidelines report very few clinical breakpoints for animal species (Toutain et al., 2017, CLSI, 2019). Therefore, investigations into the presence of AMR from isolates of animal origin have often used human clinical breakpoints for the interpretation of inhibition zone diameters (Li et al., 2014, Shin et al., 2015, European Food Safety Authority, 2018, Brisola et al., 2019). Human breakpoints may not reflect clinical resistance in isolates from animal origin, as breakpoints need to be species-specific due to differences in responses to antimicrobial administration (Toutain et al., 2017).

Another method of inhibition zone interpretation is the use of epidemiological cut-off values. Epidemiological cut-offs are used to determine non-wild type bacteria. Wild type (WT) bacteria are assumed to have no acquired or mutational resistance (European Food Safety Authority, 2018); whereas, non-wild type (NWT) bacteria are assumed to have acquired or mutational resistance and will have reduced susceptibility. The terms "resistant" and "susceptible" are reserved for clinical breakpoints that detect clinical resistance. Thus, the terms "wild type" and "non-wild type" are used for the microbiological resistance detected by epidemiological cut-offs (EUCAST, 2015).

An epidemiological cut-off detects small changes in phenotypically detectable susceptibility rather than determining clinical effectiveness. Therefore, clinical breakpoints and epidemiological cut-offs are sometimes not the same value. The epidemiological cut-off values defined by EUCAST are termed ECOFFs. The ECOFF values are determined by EUCAST through analysis of the distribution of their inhibitory zone diameters (Kahlmeter, 2014, Matuschek et al., 2014). EUCAST does not clearly state how they establish the ECOFFs for disk diffusion testing, although literature suggests that inspecting the histogram distributions by eye or the Normalised Resistance Interpretation (NRI) method may be used (Kahlmeter, 2014, Matuschek et al., 2014). Research shows that EUCAST defined ECOFFs may not be appropriate for determining NWT bacteria from animal origins (Dias et al., 2015, Silva et al., 2020). This is because the ECOFF values may cut through the normal distribution of WT isolates of animal origin.

Animal species-specific cut-off values can be used for zone interpretation using the NRI method. This method has been used to determine species-specific cut-offs for wild ungulates (Dias et al., 2015), sheep (Silva et al., 2020), and aquaculture (Smith et al., 2012). NRI is based on the assumption that the WT isolates (isolates in the "high zone") have a normal distribution (Kronvall

and Smith, 2016). The peak position of this high zone is determined using rolling means (Kronvall et al., 2003). The fraction of isolates in the high zone is calculated from this and transformed into probit values. The least-squares method defines the normal population corresponding to the WT peak (Kronvall et al., 2011). The most frequent approach was to set cut-off values at two and a half standard deviations below the mean, although other standard deviations can be used to include various percentages of WT isolates (Kronvall and Smith, 2016).

In summary, as clinical breakpoints do not exist for sheep and cattle, and human breakpoints may not reflect clinical resistance in animal species, this method of interpretation should not be used alone. There is no gold-standard for alternative interpretation methods; however, previous studies of animal isolates have used ECOFFs and cut-off values determined by the NRI method. All three methods could be used to determine the most appropriate cut-off value for isolates of sheep and beef origin.

2.3. Social science methods

To understand the decision-making processes and behaviours relating to AMU by both farmers and veterinarians, information is needed about the social mechanisms underlying these behaviours. Studies 3, 4, 5, 6 and 7 therefore used methods from the social sciences. From the introduction, it was clear that there was insufficient information available around sheep and beef farmers' and veterinarians' antimicrobial decision-making. The introduction also highlighted two areas that require more consideration during the study design of antimicrobial decision-making research: (1) the inclusion of theory; and (2) attempts to reduce social desirability bias. This section first introduces theoretical approaches to understand behaviour from both a psychological and sociological perspective. Then survey methods, text analysis, semi-structured interviews and mixed methods are discussed.

2.3.1. Use of psychological theory to understand behaviour

The application of theory to studies of behaviour has become more appreciated in recent years. There are many different theories that may be used, each include various social, cultural, or economic components. The type of theory used is dependent on the studies intended hypothesis or outcome. As of yet, there is no singular accepted theoretical model for decision-making though, the Theory of Planned Behaviour (TPB) is one of the most used social cognitive theories (Ajzen, 1991). It is particularly prominent in healthcare where it has been found to be a useful tool to understand clinical decision-making (Eccles et al., 2007, Godin et al., 2008). More recently, the TPB has been applied to veterinary research, mostly around farmers decision-making such as the treatment of mastitis (Lind et al., 2012) and AMU (Jones et al., 2015). Research has shown that intervention studies are more effective when barriers and facilitators of a guideline are pre-identified (Baker et al., 2010,

Bernhardsson et al., 2014). Therefore, use of theory is suggested for the successful implementation of guidelines.

The TPB has come under criticism from various researchers and this has been summarised by Sniehotta et al. (2014). Some of this criticism is due to the entirely rationalistic explanation of behaviour construed by the TPB (Conner et al., 2013, Sniehotta et al., 2014). More intuitive influences such as emotion and habit are excluded and there is evidence that these can predict behaviour better than TPB (Gardner et al., 2011). Furthermore, there is very little experimental validation of the TPB (Sniehotta et al., 2014, Schwarzer, 2014).

Ogden (2003) broadens the criticism of the TPB to social cognition models in general. They argue that though the models are useful to inform interventions to promote health related behaviours, the theories cannot be tested. This is because the constructs in theories are not specific enough for hypotheses to be generated. Researchers tended to use variables for different constructs by saying the same thing but in different words, which means constructs are highly correlated and not discrete. Additionally, social cognitive theories often explain very little of the variation in behaviour (Ogden, 2003).

As a single theory may be too broad to measure specific behaviours, researchers have adapted social cognitive theories to their chosen behaviour. For example, some researchers use a decomposed version of the theory where they split the original constructs into more explicit categories relating to their area of investigation (Hsu and Chiu, 2004). Others extend a theory by including additional constructs (Banas et al., 2017, Kim et al., 2016). An alternative approach is to identify relevant constructs from multiple theories and combine them into one model (Hagger and Chatzisarantis, 2014, Hagger et al., 2017). These types of models have the ability to outperform traditional social cognitive theories by bringing together sociological and psychological constructs.

One theory that conflicts with many social cognitive theories is the theory of cognitive dissonance (Festinger, 1957). Unlike the TPB which states that attitudes remain constant, cognitive dissonance theory indicates that attitudes can change. When a person's behaviour and attitudes do not align, then discomfort will arise. This leads to a change in behaviour or attitude to reduce the dissonance. A closely related theory is Bem's self-perception theory (Bem, 1972). Self-perception theory suggests that people make inferences about their values and attitudes based on observing their own behaviours. Cognitive dissonance theory and self-perception theory can be employed to explain the formation of people's attitudes, which other social cognitive theories where attitudes are static cannot do. At present, there are very few studies that make use of cognitive dissonance or self-perception theory to understand farmer or veterinary decision-making. Some examples include the compliance of farmers towards veterinary advice (Kristensen and

Jakobsen, 2011), and attitudes towards animal welfare (Peden et al., 2020). A review of the public's antimicrobial compliance behaviour identified cognitive dissonance as an influence of cognitions around AMR (Fletcher-Miles and Gammon, 2020). Yet, cognitive dissonance has not been widely explored in veterinarian or farmer decision-making around antimicrobials. Few studies have briefly referred to the theory as an explanation of their findings.

2.3.2. Use of sociological theory to understand behaviour

Much like theories of behaviour, sociological theories do not have a single overarching underpinning. There are broad schools of thought including symbolic interactionism, conflict theory and structural-functionalism. Symbolic interactionism has been used to establish the 'good farming' concept, which has become widely recognised within rural sociology (Burton, 2004). The focus of symbolic interactionism are the interactions among individuals in a society. Individuals place meanings, or symbols, onto objects, events and behaviour. Burton (2004) identified symbolic values towards farming as a measure of what constitutes a 'good farmer'. These included de-weeding and cutting hedges of roadside fields, producing high crop yields, and the appearance of crops.

Within rural sociology there are some dominant perspectives including Bourdieu's theories of habitus, field, and capital (Bourdieu, 1990, Bourdieu, 2011). The habitus are the social norms that guide behaviour or thinking. Through socialisation an individual realises unconscious dispositions to act, think, and feel in certain ways. Habitus is attained through integration into social groups such as social class, profession or gender. People will have different habitus' associated with different groups and these mix together to form their individual habitus. The field refers to how individuals construct social fields. The world may be divided up into many fields of practice such as education, profession, and law. Within each field are "rules of the game". Individuals struggle for position within a field to accumulate, trade, and control different kinds of power resources or capital. The more capital an individual has, the more powerful position they have within their field. Capital is formed of economic capital, cultural capital, and social capital. Economic capital represents the material assets an individual has. Cultural capital refers to high status cultural signs such as attitudes, preferences, knowledge and behaviours (Lamont and Lareau, 1988). With social capital individuals can accumulate resources through their connections or relationships.

In rural sociology, Bourdieu's theories of field, habitus and capital have been used to develop the "good farmer" concept. A loss of cultural capital has been used to explain farmers' lack of uptake of agri-environmental schemes in that farmers are not able to exhibit valued skills through engaging in the schemes (Burton et al., 2008). Sutherland and Burton (2011) explored the role of capital in informal exchange relationships between Scottish farmers. They

demonstrated the trade-offs between social, cultural and economic capital and how issues with labour time can affect this. Built on the work of capital within good farming, Sutherland and Darnhofer (2012) went onto examine the role of habitus and field in conventional and organic farming. They highlighted the changing "rules of the game" within farming where new symbolic values were developed and consequently cultural capital was not static. Similarly, Shortall et al. (2018) identified that farmers can have conflicting good farming identities which reflect the changing "rules of the game". Bourdieu's theories have also been used to explore farmers' medicine use practices. The routine use of anthelmintic drugs was associated with the farmers' habitus of livestock farming (Bellet, 2018). Farmers feared loss of economic and cultural capital if they did not carry out these practices. As of yet, the use of Bourdieu's theories to understand farmers' antibacterial AMU has not been explored and may be useful to understand why farmers do not always carry out best practice.

A further use of symbolic interactionism in rural sociology is the use of script theory. Use of scripts was first proposed by Goffman (1959) who used an analogy of the theatre to describe human social behaviour. Actors take on a role, and within that role certain scenarios have social scripts, pre-established patterns in behaviour that they are expected to take. Within rural sociology, script theory has been used to understand gender division (Silvasti, 2003a), good farmer identity (Silvasti, 2003b), and control of bovine tuberculosis (Enticott and Vanclay, 2011, Vanclay and Enticott, 2011). Vanclay and Enticott (2011) identified and defined four types of script that can occur:

"(1) a socially perceived routine or expected sequence of events; specifically an understanding about how things should or will unfold; (2) a catch-phrase, metaphor or allegory that is frequently recited in response to a particular issue or situation; (3) a mini-story, narrative, or parable that has particular significance in a social group and (4) a commonly used line of argument that is widely invoked in response to a particular issue or situation."

Farming can be thought of as a role and when individuals identify as a farmer there are certain scripts they can follow to feel part of a group. Scripts are not just ordered events and can be used to achieve goals such as moral accountability and establish identity (Enticott and Vanclay, 2011). For example, scripts of bovine tuberculosis meant that farmers avoided responsibility for outbreaks. It is known that farmers can push responsibility for AMU and resistance onto others and therefore scripts may be an appropriate theory to utilise (Golding et al., 2019).

2.3.3. Grounded theory

Social science methods could also be used to develop a new theory of antimicrobial decision-making. Grounded theory is a research methodology developed by Glaser and Strauss (1967), which has been almost exclusively

used for qualitative research (Charmaz, 2006). It is a useful approach when the goal is to create a framework that explains a human behaviour. Therefore, it may be a suitable approach to understand farmer and veterinarian behaviours towards antimicrobials. Grounded theory involves the collection and analysis of data to formulate a theory. The researcher does not start out with a well-defined research question (Wuest, 2012). Instead, the researcher starts with a domain of study and identifies the research problem from the data. The data collection and analytical processes involved in grounded theory are described in the following sections.

2.3.3.1. Study samples and data collection

For grounded theory, theoretical sampling is used, where sampling occurs during the data collection and analysis process (Robinson, 2014). Data from a convenience sample are first collected and analysed. New participants are identified based on findings from the analysed data which need to be clarified (Wuest, 2012). For grounded theory, the data collection process is complete when data saturation is reached. The concept of data saturation was introduced by Glaser and Strauss (1967) as when no new data are obtained to develop categories.

2.3.3.2. Data analysis

Grounded theory uses the constant comparative method for analysis of data (Maykut and Morehouse, 1994). This is where the data within a dataset is compared during each stage of analysis. The interview transcripts (other data sources could also be used) are constantly compared with one another so that categories are reviewed and refined after each subsequent transcript. There are three steps to the coding process: initial coding, focussed coding and theoretical coding (Charmaz, 2006). Initial coding is the first step where many codes are produced. Focussed coding then narrows down the number of codes by selecting the most suitable ones. Finally, connections are made between codes to produce categories. Categories can then be related to each other to establish a theoretical concept. Diagramming the theory can help to visualise how the categories relate to each other theoretically (Wuest, 2012). Whilst most often used in a grounded theory design, the constant comparison analysis method can be used alone.

2.3.4. Survey methods

Quantitative survey research is a key method for collecting, organising and analysing data. Surveys are commonly used in the social sciences to measure people's attitudes and behaviour. It allows for large sample sizes as they are relatively easy to disseminate to a large target population. Therefore, quantitative surveys are useful when generalisations for a given population are required. However, surveys rely on self-report as researchers are unable to observe the attitudes or behaviours of respondents directly as in experimental research designs.

2.3.4.1. Methods for measuring socially undesirable behaviour

The use of antimicrobials in agriculture is under immense scrutiny and has become highly political (O'Neill, 2016). Farmers may not feel comfortable revealing their true AMU, and veterinarians may not feel comfortable disclosing their true antimicrobial prescribing patterns. This makes it difficult to obtain reliable data from direct questioning as AMU and prescribing may be underreported. There is also the possibility of non-response bias, with those carrying out the sensitive behaviour choosing not to participate in the survey. The method of survey delivery may help with improving data validity. Less intrusive methods could be used such as anonymising the survey and conducting surveys online rather than face to face or over the phone (Chang and Krosnick, 2009, Kreuter et al., 2009). Additionally, there is a growing body of research around the use of indirect questioning to measure sensitive issues in order to combat issues with bias and validity. Some of these techniques include the list experiment, randomised response, and factorial survey design. The benefits and problems of each technique are discussed below.

The list experiment technique, first introduced in 1979, has mainly been used in political science (Raghavarao and Federer, 1979, Kuklinski et al., 1997). For this technique, respondents are asked how many statements within a list apply to them. The respondents are split into two groups and one of the groups receives an extra statement within the list. This extra statement is the sensitive question. The respondent will say how many of the statements are true for them without revealing which of the statements in the list are true. The researcher can estimate the prevalence of the sensitive behaviour by taking the difference between the two means of the two groups. This technique has had rising application in social research due to its easy administration. However, researchers have had varying success with the method (Gosen, 2014). As the respondents are split into two groups, a large sample size is required for analysis otherwise there will be low statistical power for hypothesis testing. The sample sizes for surveys with veterinarians or farmers as the target population is typically small and so this technique may not be appropriate (Busani et al., 2004, Cattaneo et al., 2009, Visschers et al., 2015, Higham et al., 2018).

The randomised response technique was first introduced by Warner (1965). Questions are split into sensitive and insensitive questions and these are numbered. For this technique the respondent requires a method to randomly select whether a sensitive or insensitive question is to be answered. The randomised response technique has been shown to outperform the list experiment in terms of bias reduction (Rosenfeld et al., 2016). However, as with the list experiment technique, the randomised response technique requires a large sample size because respondents only answer a proportion of the questions. Randomised response technique also relies on the respondents' adherence to the study design. Previous research suggests that

non-compliance and non-response can be high (Rosenfeld et al., 2016, Chuang et al., 2021).

The final technique for measuring sensitive topics discussed here is the factorial survey approach. It was first developed to measure attitudes and judgements but has more recently been used to measure behavioural intentions (Rossi et al., 1974). Some examples include the intention to hire an employee (Protsch and Solga, 2017, Shi et al., 2018) and cheating behaviours (Freiburger et al., 2017). In this approach, respondents are presented with a series of vignettes. Each vignette contains multiple variables and these variables are manipulated and randomly allocated to respondents. As multiple variables are manipulated at the same time, respondents are less aware of the changes to the variables and this reduces the social desirability bias. The unit of analysis is the vignette and as respondents rate multiple vignettes, a relatively small sample of respondents is required compared to other techniques (Wallander, 2009). Previous research into the validity of factorial surveys indicate that factorial surveys and their corresponding field experiments give similar relative effect sizes, direction, and statistical significance (Eifler, 2010, Petzold and Wolbring, 2019). Factorial surveys have been recommended for medical decision-making (Ludwick et al., 2004) and in this domain they have mainly be used in nursing research (Lauder et al., 2001, Rattray et al., 2011, Killick and Taylor, 2012, Chatfield et al., 2017). However, to the author's knowledge, factorial surveys have not been used in veterinary research.

2.3.4.2. Overview of the factorial survey approach

The factorial survey approach measures human judgement by combining both experimental design and survey techniques. A factorial survey will therefore have the high external validity of survey research and the high internal validity of experimental design (Evans et al., 2015)

The respondents are presented with vignettes, which should mimic a “real-life” scenario. Factors that should be included within the vignette can be identified from previous literature, qualitative study or practice experience (Taylor, 2006). The vignettes comprise of several independent variables (dimensions) that contain different levels. The order of the dimensions in the vignette should remain the same, but the levels should be altered in a randomised manner. As multiple dimensions vary at the same time, respondents have to make trade-offs between each dimension (Auspurg et al., 2014). Therefore, the relative importance of factors towards a decision can be revealed.

The multiple levels within variables can lead to a large number of individual vignette versions – sometimes referred to as a “vignette universe”. There is no rule of thumb on how many independent variables should be included, but

a limit of seven variables has been suggested due to cognitive psychology research findings of short-term memory capacity (Josua et al., 2016).

The “vignette universe” is calculated by multiplying the dimension levels together. Previous literature has shown the vignette universe can be extremely large (Wallander and Molander, 2014). Due to this large number, respondents are asked to rate only a proportion of these vignettes. It is suggested that no more than ten vignettes should be rated per respondent (Auspurg and Hinz, 2014). These vignettes are randomly selected from a sample of the original universe, where all dimension levels have equal probability of occurring.

The most common strategy for vignette sampling in factorial survey research is random sampling with replacement (Wallander, 2009). However, more recently, a D-efficient design has become more popular (Bos-Touwen et al., 2017, Chatfield et al., 2017). A D-efficient design minimises intercorrelation among the dimensions of the vignettes, whilst maximising the variance and balancing the frequency of vignette levels (Kuhfeld, 2005). The result is a higher statistical power and efficiency. The maximum D-efficiency is 100, where over 90 is considered a good D-efficient design.

2.3.5. Text analysis

People's opinions, attitudes and behaviours can be examined through their written text. With technological advancements and the increase in the use of the internet, the analysis of text has become more and more feasible. This has led to the availability of new data sources and the employment of new data analysis methods. This section describes the use of online texts as a data source and how these texts may be analysed.

2.3.5.1. Online data

There is a growing body of research interested in the analysis of online texts. In GB, 93% of households had access to the internet and 87% of adults used the internet daily or almost daily in 2019 (Office for National Statistics, 2019). Over two-thirds used the internet to use social media and 63% to look up health-related information. This provides a wealth of information on people's opinions and behaviour on Facebook, Twitter, blogs and comments sections on news sites for example. The availability of online data on a massive scale has allowed quantitative researchers to investigate text as big data. Quantitative researchers have used text as big data to detect outbreaks of influenza (Ginsberg et al., 2009), detect the onset of depression (Reece et al., 2017) and evaluate the consequences of electronic cigarette use (Chen et al., 2015).

Online texts can also be analysed qualitatively. Some areas where qualitative researchers have used online data include male infertility (Hanna and Gough, 2016), recreational drug use (Soussan and Kjellgren, 2014) and mental health

(Gough, 2016). These are particularly sensitive issues where there may be high social desirability bias if a researcher asked the participants questions directly. This data typically comes from online discussion forums. Discussion forums can be described as areas where there are "opportunities to give and receive emotional and informational support, share experiences, and ask questions" (Seale et al., 2010). The role of the researcher within these forums can lie on a spectrum from outside observer to involved researcher (McKenna et al., 2017). An outside observer adopts a passive approach to the study, whereas an involved researcher may create an account and create posts on a website, for example.

One of the main advantages of internet-mediated research is that a large amount of easily obtainable data exists. However, there tends to be potentially too much data for in-depth qualitative research, particularly as a lot of this data is noise. It is recommended that a filtering technique is used to only obtain useful information so the researchers focus on specific topic-based forums and use search queries to filter the text (McKenna et al., 2017). The smaller study samples allow for a more in-depth examination of the discussions and prioritise intensive rather than extensive analysis (Hanna and Gough, 2016). For quantitative analysis, such large datasets mean that manual coding can be time consuming and logistically difficult. The difficulties of manual coding led to the development of computer software to carry out the coding of texts, which has developed into the field of natural language processing (NLP).

2.3.5.2. Natural language processing

NLP refers to a range of computational techniques to analyse texts for linguistic analysis. The majority of text online is in an unstructured form, which means it is not machine-processable in its direct form. NLP aims to process this data and interpret it as humans do by attempting to map words or phrases into contexts. First, paragraphs are broken into "tokens" (Chary et al., 2019). A single word can be considered a token. A string of words can also be considered a token if they describe one concept. For example, "phone" and "mobile phone" could both be considered as single tokens. The token is then mapped onto a lemma, a base word that stands at the head of a definition in a dictionary. For example "ewe" may be mapped onto the lemma "sheep". Then the lemma is mapped to a concept or topic (Chary et al., 2019).

The mapping of tokens to lemmas and concepts can use rule-based, statistical, or hybrid approaches. Rule-based methods are useful when using highly specific data, but may not be scalable and are often customised to a specific task. Machine learning methods used for statistical NLP require prior data for training, but perform well as they "learn" from the data (Nadkarni et al., 2011). Machine learning NLP can be made more accurate by providing

more data to learn from. The rule-based and statistical approaches are complementary, which is why some researchers use hybrid approaches.

The type of algorithm used to analyse online text is dependent on the aims of the research. NLP can be used for machine translation, automatic summarisation, and question-answering, for example. For social media research, semantic analysis is often used (Farzindar and Inkpen, 2015). Semantic analysis is the process of drawing meaning from the text. One type of semantic analysis NLP method is topic modelling. Topic modelling uses statistical algorithms to infer the main themes from a collection of documents (Blei, 2012). It does not require prior labelling or annotation of the documents. There are different types of topic model. Latent Dirichlet Allocation (LDA) works on the intuition that each document has multiple topics which are displayed in different proportions, and each word within the document is drawn from one of the topics. The selected topic is chosen from the per-document distribution over topics (Blei, 2012). It can be used to determine the hidden structure of documents by determining the most frequent topics and illustrating each topics most frequent words. However, words that do not have topical content (e.g. function words such as "it", "but", "then") are excluded from analysis. If words are examined from a psychological perspective, then the use of these function words is important because they can reflect psychological markers (Pennebaker et al., 2003).

A different semantic analysis NLP method is Language Inquiry and Word Count (LIWC). It is a textual analysis programme that contains a validated internal dictionary to define which words are counted into specific categories (Pennebaker et al., 2015b). This dictionary was developed through extensive manual coding. The newest dictionary in LIWC can accommodate for "chat speak" and will even code emoticons, which is useful for the analysis of social media texts (Pennebaker et al., 2015b). There are over ninety categories which include linguistic dimensions (e.g. pronouns, articles, and prepositions), psychological constructs (e.g. social, affective, and cognitive processes), and personal concern categories (e.g. work, leisure, and money). The programme returns a set of scores for each category based on the frequency of words that appear in the document. There are also four summary variables that are made from a combination of the other categories which capture the underlying style and tone of the text. LIWC can be used for sentiment analysis as it can detect positive, negative, and neutral tones in the text and categorise words accordingly.

The original aim of LIWC was to capture the psychological processes and the content of what people were writing about. Since then, LIWC has been used for many studies across different disciplines and the categories have been validated across numerous psychological domains (Tausczik and Pennebaker, 2010). LIWC had been validated for the identification for emotional

expression of text, although it will sometimes over-identify emotional expression (Bantum and Owen, 2009, McDonnell et al., 2020). Additionally, multiple studies have shown that first person pronoun use is correlated with depression (Holtzman, 2017), and LIWC can be used to measure this (Rude et al., 2004). Therefore, in medical research, LIWC has mainly been used as a method to analyse text to detect psychological illness and anxiety in patients (Xu and Zhang, 2016, Kornfield et al., 2018, Pan et al., 2020). In terms of veterinary research, LIWC has been used to study pet bereavement (Lyons et al., 2020) and the effectiveness of pet adoption profiles (Markowitz, 2020), but has not been used to study farmer or veterinarian behaviour to the author's knowledge.

2.3.6. Semi-structured interviews

The aim of qualitative methods is to understand in-depth the experience, values, attitudes, or perspective of the participant in order to answer the research question. Qualitative methods can be used to study human behaviour that cannot be quantified. They are valuable methods when little is known about the topic under study. There is growing appreciation of the value of qualitative research and qualitative methods have been successfully applied to the health sciences (Broom et al., 2014) and veterinary science (Kaler and Green, 2013, Ruston et al., 2016). Although, the presence of qualitative research in veterinary science journals is still rare compared with quantitative.

The semi-structured interview is the middle-ground between structured interviews and unstructured interviews. In a structured interview there are a set of pre-determined questions that are used for each interview. Unstructured interviews do not have any pre-determined questions and the interview is carried by the conversation with the participant. The semi-structured interview uses an interview guide which is developed and refined as more participants are interviewed. The semi-structured interview is structured enough to know the research question will be answered whilst being flexible enough to obtain new information. It is a suitable method for studying issues that participants are not used to talking about, such as their perceptions or values, or sensitive topics (Kallio et al., 2016).

The semi-structured interview guide is usually informed by existing literature or empirical knowledge where literature is scarce (Kallio et al., 2016). Well-formulated questions are required in order to obtain rich data. Questions should be clearly worded, open ended, neutral, and should not be leading. It is important to pilot test the interview guide to ensure this is the case. The interview guide consists of a few key questions which each feature some sub-questions, or prompts, to guide the participant and obtain greater detail on responses. Spontaneous questions can also be asked to build on something interesting that the participant has revealed or to clarify meaning.

It is beneficial to start the interview with some warm-up questions to make the participant feel at ease (Kallio et al., 2016). More sensitive questions should be asked toward the end of the interview once rapport has been built between the interviewer and participant (Leech, 2002). Rapport can be built through the interviewer introducing themselves to the participant and telling them about the study before the interview starts, and maintaining a non-judgemental conversational tone throughout the interview (DeJonckheere and Vaughn, 2019). It can be useful to end the interview guide by asking the participant if there is anything else they would like to discuss (McGrath et al., 2019). The interview should be conducted somewhere which is convenient for the participant (DeJonckheere and Vaughn, 2019). It should also be a place where the participant is comfortable talking about a sensitive topic with minimal disruptions. Often, this is in the participant's home. Most interviews are audio-recorded and so a quiet interview place is beneficial for a clear recording.

Once the audio data has been collected, the process of data transcription begins. Transcription involves listening back to the audio recording and writing down the spoken words. There are different types of transcription including verbatim, edited and intelligent. Verbatim is the most common type of transcription for qualitative interview studies (McGrath et al., 2019). This is where the written words are an exact match to the audio recorded words and other cues such as laughter and pauses are considered. Transcripts need to be checked against the audio recordings for mistakes that may occur.

2.3.6.1. Thematic analysis

Analysis of qualitative data involves the coding of words, sentences or paragraphs into categories. The code gives that piece of text an interpretation or meaning. By coding the data, clusters of data relevant to a particular interpretation can be identified. The visualisation of the coding process is often facilitated by a computer programme such as NVivo (NVivo qualitative data analysis Software; QSR International Pty Ltd. Version 12, 2018). The analysis is reflexive in that it is directed by how the researchers interpret the data and what they want to get out of the data. Thus, the data is revisited many times as new questions arise from the data, and so qualitative data analysis is also an iterative process (Srivastava and Hopwood, 2009, Chowdhury, 2015).

Thematic analysis is widely used for qualitative interview studies (Braun and Clarke, 2006). In particular, thematic analysis has been a popular method for qualitative analysis of veterinary antimicrobial decision-making (Coyne et al., 2014, Coyne et al., 2016, Bourély et al., 2018, Golding et al., 2019). The advantage of thematic analysis is that it is a flexible method that is not theoretically bound (Braun and Clarke, 2006). Instead, the analysis is driven by a particular analytical question. The first step of thematic analysis is

familiarising yourself with the data (Nowell et al., 2017). This involves repeatedly reading the data to search for patterns and meanings. Then, initial codes will be generated. Coding can be either deductive or inductive (Braun and Clarke, 2006). Deductive coding is where a codebook is already defined before the analysis is conducted. An inductive approach is where categories are derived from the data and new theories or hypotheses are developed from this. Once all data is coded, the codes of interest are selected and collated to produce themes. Themes identification can take a semantic approach in which the explicit meanings of the data are identified (Braun and Clarke, 2006). Alternatively, theme identification can take a latent approach which examines the underlying ideas within the data. The themes are then reviewed and refined. Themes need to be discrete yet broad enough to contain multiple codes of text (Nowell et al., 2017). Once the themes are reviewed, they need to be defined and given a name. Finally, the analysis needs to be reported. The prevalence of themes are often represented using a non-quantifiable measure such as "the majority of participants" or "many participants" (Braun and Clarke, 2006). It is important to include direct quotes from the data to provide a narrative and convince readers of the validity of the study (Nowell et al., 2017).

2.3.6.2. Qualitative content analysis

Qualitative content analysis is an analytical method similar to thematic analysis in that it is a non-linear coding process. The first steps in content analysis is to identify the research question and define the units of analysis. For semi-structured interviews, the unit of analysis would usually be the transcribed data. The researcher then familiarises themselves with the data (Roller, 2019). Initial coding of text is carried out to give it a descriptive label. The categories can then be identified from the codes and patterns can be identified across categories.

The main difference between content analysis and thematic analysis is that content analysis puts the data into categories, whereas thematic analysis generates themes from examining the relationships and meanings in the codes and categories (Crowe et al., 2015). Therefore, content analysis tends to be more descriptive and thematic analysis is more interpretative. Whilst content analysis can take a deductive or inductive approach (Hsieh and Shannon, 2005), content analysis tends to take a more deductive approach and thematic analysis tends to take a more inductive approach (Crowe et al., 2015). This means that research using content analysis focusses on the manifest content of interviews, as opposed to the latent content which is often the focus of thematic analysis.

Qualitative content analysis has been employed less in veterinary research compared with thematic analysis (Rell et al., 2020). This is probably because of the more interpretive approach of thematic analysis allowing for in-depth

examination of farmers' and veterinarians' opinions and behaviours. A more descriptive approach to analysis does make content analysis useful when aiming to make comparisons in the data, and where representation of what was actually said by participants is important (Crowe et al., 2015).

2.3.7. Mixed methods research

Mixed methods research can be defined in multiple ways. Johnson et al. (2007) obtained the definitions of mixed method research from prominent researchers to offer a definition of mixed methods research as research that "combines elements of qualitative and quantitative research approaches for the broad purposes of breadth and depth of understanding and corroboration". They also state that a mixed methods study is when multiple methods are used within a single study; whereas, a mixed methods programme is when mixing occurs across a group of closely related studies. Thus, this project could be described as a mixed methods programme, where qualitative methods and quantitative methods are used in separate studies to help form a more complete understanding of how antimicrobials are used in sheep and beef farms in the UK. Within the group of studies that make up this mixed methods programme, two are mixed methods studies (Study 1 and 6).

Bryman (2008) explored the rationale for using mixed methods by carrying out content analysis on published papers using this approach. The most common rationales given were enhancement, sampling, completeness, and triangulation. Enhancement is the strengthening of the significance of the study by mixing of methods (Collins et al., 2006). Sampling refers to participant enrichment. For example, where a qualitative method is used on a small sample and then a survey is conducted to enrich the number of participants. Completeness means using mixed methods to provide a comprehensive picture of the study.

The concept of triangulation was introduced by Campbell and Fiske (1959) and Webb et al. (1966) who were concerned about the validity of conclusions produced from the data. Each method has their own weaknesses, but by using multiple methods and comparing the results, the aim was to minimise these weaknesses to provide valid conclusions. Thus, the initial use of triangulation was to use two different methods to produce similar results in order to enhance the validity of the research. Since then the term 'validity' has often been replaced with 'credibility' to reflect that triangulation tends to include qualitative methods as well as quantitative. Now, multiple types of triangulation exist and as well as the methodological triangulation mentioned above, there is also data triangulation, investigator triangulation, and theory triangulation (Denzin, 2006). Hence triangulation can be used to minimise the bias inherent in using single methods, observers, and theories.

In 2017, editors at the Journal of Mixed Methods Research recommended the discontinuation of the use of the term triangulation (Fetters and Molina-

Azorin, 2017). They argued that the term triangulation had too many meanings and was too broad to the point that the term becomes meaningless. There were better terms which describe the design in more detail. Morgan (2019) built on this by offering a replacement to the use of triangulation, proposing that comparisons between qualitative and quantitative methods to answer the same research question can result in convergence, complementarity, and divergence. Convergence refers to when the results from the two methods are similar, which increases the credibility of results. Complementarity refers to when qualitative and quantitative methods are used together to gather more information than you could with either method alone. Divergence refers to when there are differences in the results from the two methods (Morgan, 2019). Fetters and Molina-Azorin (2019) refine this by defining complementarity as "when the compared qualitative and quantitative data illustrate different, nonconflicting interpretations" and adding a further outcome, expansion. They define expansion as "when the compared qualitative and quantitative data provide both a central overlapping as well as a broader nonoverlapping interpretation".

A final consideration when employing mixed methods research is how to integrate and report the results from the qualitative and quantitative data. Fetters et al. (2013) mention the approaches of integrating through narrative; integrating through data transformation; and integrating through joint displays. Integrating through narrative concerns describing the results of the qualitative and quantitative analysis using a written narrative. This can be by reporting the qualitative and quantitative results in different sections within the same report (contiguous approach), or reporting results theme by theme (weaving approach). Alternatively, the results can be reported in separate reports (staged approach). Integrating through data transformation is where one type of data is converted to another type. Integrating through joint displays refers to visualising the results of the qualitative and quantitative results (Fetters et al., 2013). During this integration the assessment of the fit of the data should take place. The possible outcomes proposed by Morgan (2019) and refined by Fetters and Molina-Azorin (2019) of convergent, complementarity, expansion and divergent results can be assessed. Morgan (2019) recommends a means of reporting the results by using a cross-tabulation of which has been adapted to include the expansion outcome (Table 3). This cross-tabulation technique was used to report the results of the mixed-methods Study 6 and Study 1.

Table 3: A system to compare qualitative and quantitative results (Adapted from Morgan (2019))

	Qualitative results	Quantitative results
Convergent results	…	…
Complementarity qualitative results	…	
Complementarity quantitative results		…
Expansion results	…	…
Divergent results	…	…

2.4. Methods used for the project

Overall, this thesis is a mixed-methods programme which consists of quantitative, qualitative, and mixed-methods studies. This introduction to methods ends with a brief overview on the methods used for the seven studies that make up this project. The methods are also summarised in a methods scheme in Figure 2. A detailed account of the methods used in each study are described later within their individual chapters.

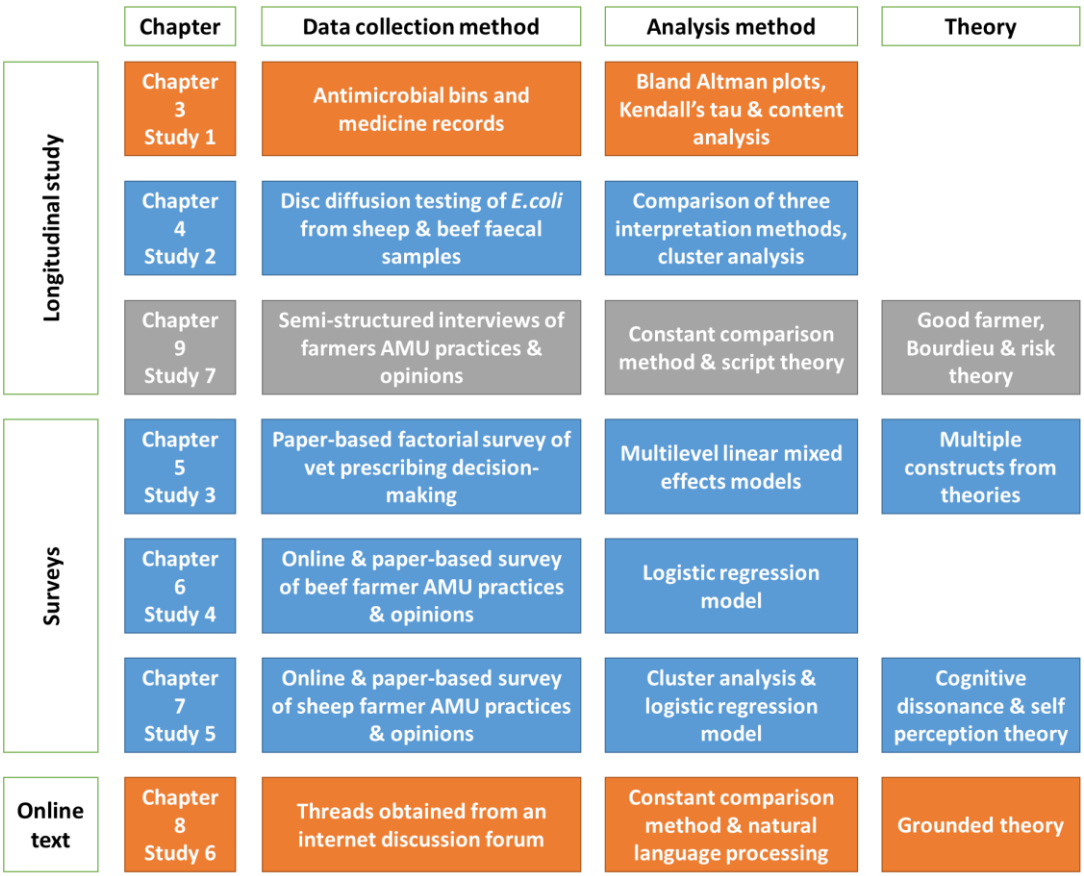


Figure 2: Methods used for each study in the project. Blue shading represents quantitative studies, grey represents qualitative studies and orange represents mixed methods studies.

Chapter 3: Study 1 aimed to evaluate sheep and beef farmers' antimicrobial medicine records against the contents of antimicrobial bins. Bland-Altman plots and Kendall's tau were used to assess agreement between the two methods. A qualitative interview was conducted with farmers at the end of the study. Qualitative content analysis was carried out to determine the barriers and benefits of each method.

Chapter 4: Study 2 used disk diffusion testing to investigate antimicrobial susceptibility of presumptive *E. coli* isolated from sheep and beef cattle. The results were interpreted using human clinical breakpoints, ECOFF values and specie-specific breakpoints. Cluster analysis was conducted to identify patterns in AMR.

Chapter 5: Study 3 aimed to investigate veterinarian decision-making when prescribing antimicrobials to sheep and beef farmers. The study used a factorial survey method to reduce social-desirability bias. The factors that were under study were chosen through inspection of relevant social-cognitive theories. Multilevel mixed effects models were used to determine the associations of factors on veterinarians' decision to prescribe antimicrobials.

Chapter 6: Study 4 used an online and paper-based survey to understand beef farmers' practices and opinions on AMU. A logistic regression model was used to determine associations with the proportion of cattle treated with antimicrobials for pneumonia.

Chapter 7: Study 5 used an online survey to investigate the association of past behaviour on sheep farmers' attitudes towards antimicrobials. Cluster analysis was used to group observations together based on farmers' ratings of sixteen statements relating to attitudes towards antimicrobials. A logistic regression model was used to determine the association of past practices on antimicrobial attitude group.

Chapter 8: Study 6 aimed to understand farmers' decision-making around prophylactic AMU in neonatal lambs. The study used data from online discussion forums and used a grounded theory design. Data was analysed quantitatively using natural language processing and qualitatively using the constant comparative method. The results were integrated using the framework proposed by Morgan (2019).

Chapter 9: Study 7 aimed to understand sheep and beef farmers' perception of risk around AMU and resistance. Transcripts from thirty-four semi-structured interviews were analysed using the constant comparative method. The results were interpreted using concepts of risk theory, script theory and good farming.

2.4.1. Target and source populations for the studies

Studies 1, 2, 4, 5, and 7 had the same target population and used samples from the same source population. A schematic is presented in Figure 3 to describe the sample population for each study. Briefly, the target population was all sheep and/or beef farmers in the UK. The source population for Studies 4 and 5 were farmers who supplied beef to two abattoirs and farmers who supplied lamb to two abattoirs, respectively. The source population for Studies 1, 2 and 7 were farmers who responded to either of the survey studies and indicated that they would be willing to participate in further AMU research.

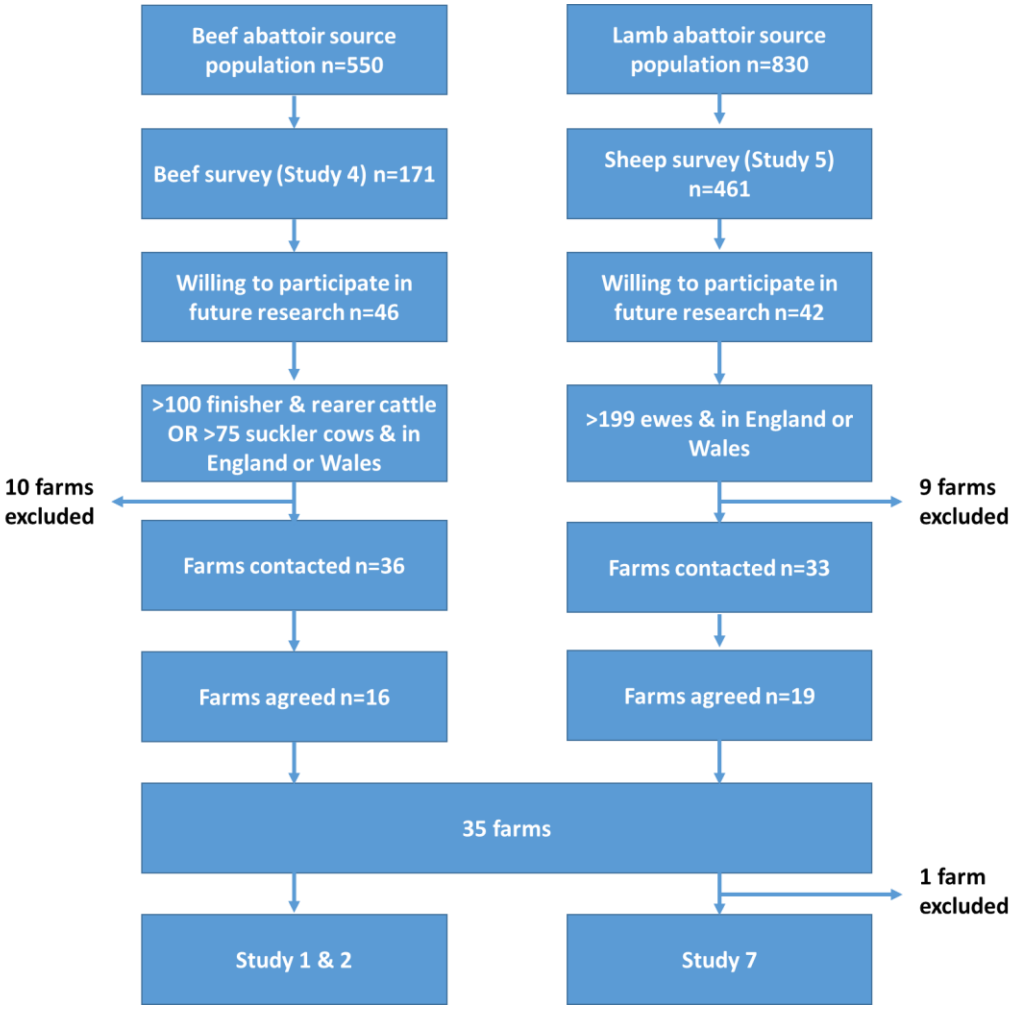


Figure 3: Schematic for the study population of studies 1, 2, 4, 5 and 7

The locations and size of farms taking part in the longitudinal study are presented in Table 4.

Table 4: Location of farms and number of animals (at time of first visit) on farms taking part in the longitudinal study

Farm	Farm Location	N beef cattle (all ages)	N ewes
1	West Midlands	220	0
2	West Midlands	205	370
3	West Midlands	281	900
4	Wales	125	750
5	South West England	2240	0
6	West Midlands	172	350
7	West Midlands	342	0
8	South West England	500	0
9	South West England	218	1058
10	Wales	236	840
11	Wales	93	550
12	Wales	0	250
13	Wales	109	584
14	South East England	198	800
15	Wales	39	538
16	Wales	41	500
17	Wales	179	1850
18	Wales	600	800
19	West Midlands	107	0
20	Wales	161	582
21	West Midlands	0	300
22	South West England	49	480
23	West Midlands	157	520
24	South West England	64	560
25	South West England	209	600
26	North East England	200	500
27	North West England	420	0
28	South West England	241	0
29	Wales	0	300
30	Wales	145	466
31	Wales	23	360
32	Wales	564	1600
33	West Midlands	285	0
34	West Midlands	0	600
35[b]	Wales	40	425

[b] Not part of Study 7.

Studies 3 and 6 used different target populations. The target population for Study 3 was all veterinarians who practise in the UK and spend some time working sheep and beef cattle. The exact number of veterinarians this criteria applies to is unknown. There are around 24,000 practising veterinarians in the UK and the RCVS survey of the veterinary profession indicated that 3.2% and 11.7% of veterinarians worked in farm animal or mixed practices, respectively (RCVS, 2019, Institute for Employment Studies, 2020). Not all farm veterinarians or mixed veterinarians will work with sheep or beef cattle. On the RCVS website there is the option to filter veterinary practices by the animals treated. Therefore, the source population were veterinarians who

worked in veterinary practices that indicated they treated sheep and cattle on the RCVS website.

For Study 6, the study sample came from an online discussion forum. The source population was sheep farmers who posted on the forum. Because of the unobtrusive nature of the data collection and the origin of the data, it was not possible to obtain information on the number of sheep farmers on the forum. There were over 45,000 active members covering all types of farming. The study sample (i.e. the number of threads) was determined by data saturation.

2.4.2. Longitudinal study design

Studies 1, 2, and 7 were all part of the same longitudinal design in which 35 farms were visited three times. The longitudinal design is presented as a schematic in Figure 4 to provide an understanding of how these three studies are linked.

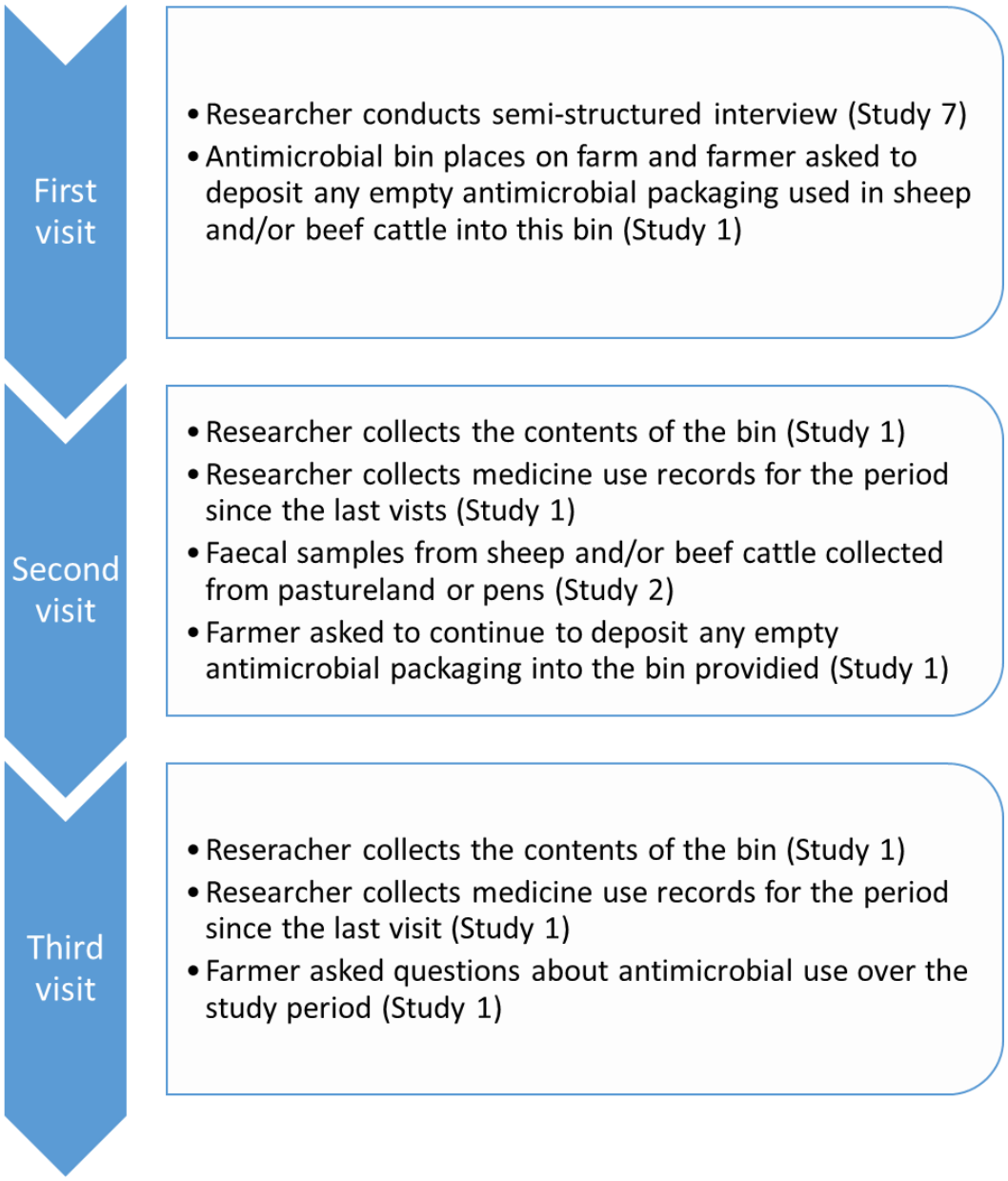


Figure 4: An overview of the longitudinal study design

3. Study 1: Evaluation of the use of antimicrobial bins and medicine records to quantify AMU on sheep, beef, and mixed species farms

3.1. Abstract

There is currently a lack of robust data on AMU on sheep and beef farms in the UK, particularly for farms with mixed species. Quantification of AMU on mixed species farms is reliant on accurate farmers' records as veterinary prescription data does not provide information at the species level. This study aimed to evaluate sheep and beef farmers' antimicrobial recording practices by comparing quantities of antimicrobials measured from medicine records and antimicrobial bins, and identify barriers and facilitators of the AMU collection methods. Thirty-five farms were followed for over a year period. Farmers were asked to record their antimicrobial treatments and deposit empty antimicrobial packaging into a bin. They were also asked to qualitatively evaluate their recording practices and use of the bin over the study period. Bins and medicine records were collected and the mass of active ingredient (mg) was calculated for each collection method. The level of agreement between the two AMU collection methods was measured using non-parametric parameters. The bins were 29-87% more likely to measure more AMU than the medicine records (p=0.003). Sheep farmers often missed neonatal lamb treatments off their medicine records, with a median of 32.5 missing treatments per farm (IQR=18-130). Of the mixed species farms, 28% of treatment entries were missing the species used in. Farmers thought the bin was easy to use and identified contextual barriers to accurate medicine recording, such as difficulties with recording in the field and animal identification, especially for sheep. This study demonstrates that medicine records may under-represent actual AMU on sheep and beef farms and provides some recommendations on how to make quantification of antimicrobials on sheep, beef, and mixed species farms more feasible.

3.2. Introduction

To understand the links between AMU and AMR, robust data on how antimicrobials are used on farms is required (UK Government, 2019). The most recent UK annual report on veterinary AMU reports beef farm AMU using a small sample, representing 9.6% of the slaughter cattle for the UK (VMD, 2020b). The farm level AMU of sheep farms was not reported. Additionally, many farms were excluded in the calculations of beef farm AMU due to the presence of sheep on the farm. The co-existence of sheep and beef cattle on farms creates difficulties when calculating AMU as it is unknown which species antimicrobials are used in from veterinary prescription data alone. On-farm medicine records are required to determine which species an

antimicrobial has been used in. There is currently no central location to collate on-farm medicine records, so at present veterinary prescription data is the only option for antimicrobial quantification at the national level.

An electronic medicine book for cattle and sheep is now being developed by AHDB and DEFRA to provide a national data hub for medicine use (AHDB, 2020a). Farmers in the UK are legally required to record the name of the product, date, quantity, withdrawal period and identification of the animals treated when administering an antimicrobial to a food-producing animal (UK Government, 2013). At present there is no set way of record keeping and farmers may choose to record using a paper-based medicine book or computer-based using a spreadsheet or computer programme. As discussed in Chapter 2, previous studies evaluating the quality of farmers' medicine records revealed that data was often missing or inaccurate (Menéndez González et al., 2010, Trauffler et al., 2014). These evaluation studies were conducted on single species farms and it is anticipated that there will be further issues with mixed species farms. For example, lack of indication of the species the antimicrobial was used in. There has not yet been an evaluation of farmers AMU records on mixed species farms. Furthermore, it is known that AMU practices can differ between countries due to cultural differences (Visschers et al., 2015, Visschers et al., 2016b). Previous research suggests that sheep farmers in the UK do not often keep health and production records (Kaler and Green, 2013). However, an evaluation of antimicrobial recording practices of farmers in the UK has not been conducted before. This is important to ensure the new electronic medicine book is effective.

There are several methods that can be used to evaluate against medicine records, one of which is the use of a bin to deposit used antimicrobial packaging into. Bins have an advantage over veterinary sales records as they measure the amount of antimicrobials that have actually been used on farms rather than the amount of antimicrobials that have been prescribed. Previous studies suggest that the use of bins performs well when there is a long term period of study (Redding et al., 2014) and has better compliance by farmers than medicine records (Carson et al., 2008b). Furthermore, the bins have been shown to give higher estimates for AMU than farmers' records (Nobrega et al., 2017, Pucken et al., 2021). Therefore, the bin method may be ideal to evaluate medicine records against if the medicine records are anticipated to be inaccurate. Although Carson et al. (2008b) discussed the overall feedback from farmers on the use of the bins and medicine records, this data was not systematically collected and analysed. Further investigation is needed to understand farmers' compliance with medicine recording and the bin method.

Previous evaluations of methods to collect AMU data have predominantly been quantitative (Carson et al., 2008b, Redding et al., 2014, Nobrega et al.,

2017, Antillón et al., 2020, Pucken et al., 2021). These studies showed where AMU differed between data collection methods, and identified which method seemed to perform best in different situations. However, it is still not known why these differences in data collection methods exist. For example, Nobrega et al. (2017) states that a limitation of their study of AMU on dairy farms was that reasons for the absence of medicine records were not available. Qualitative methods could be used to understand the experiences of farmers taking part in antimicrobial data collection studies and explore the possible differences in methods. This could be used in combination with a quantitative evaluation of data collection methods to provide a more complete understanding of antimicrobial data collection methods used on farms.

The previous quantitative comparisons of AMU data collection methods have often used correlations to measure the agreement between methods (Redding et al., 2014, Hope et al., 2020). However, correlations only measure the strength and direction of the association between two measurements. This can lead to inappropriate conclusions being drawn about the agreement of two methods. Measurements of agreement need to detect the discordance, bias, and scale between methods (Van Belle, 2008).

Bland-Altman plots are useful to visualise the scale and bias between two methods (Bland and Altman, 2010), but this does not give parameters such as confidence intervals and p-values to quantify the levels of agreement. One method of measuring discordance, bias, and scale is through the use of rank parameters of Kendall's T_a and median differences (Newson, 2019). Rank parameters are less influenced by outliers and are robust to non-linearity, which is a problem encountered in measuring farm AMU as there is usually a small set of high AMU farms (Davies et al., 2017, Hyde et al., 2017). Kendall's T_a and median differences have been used in healthcare settings to measure the agreement between model-estimated prevalence and registered prevalence of arthritis and hypertension (Pugliese et al., 2016, Gardiner et al., 2018). Some examples of where Kendall's T has been used in veterinary medicine include to measure the agreement between methods of *Toxoplasma gondii* antibody detection (Gazzonis et al., 2019), and to measure the agreement between evaluations of lameness in horses (Leelamankong et al., 2020). However, in previous research Kendall's T is usually reported without confidence intervals and is therefore not informative enough to prove that the data rejects or accepts the null hypothesis (Newson, 2002).

The aims of this study were to: (1) compare quantities of antimicrobials measured from sheep and beef farmers' medicine records and bin contents by evaluating the levels of agreement; and (2) investigate the reasons why there were differences or similarities between the two methods. It is hypothesised that medicine records will measure less AMU than antimicrobial bins.

3.3. Methods

3.3.1. Participant recruitment

Farmers identified for participation in the study were those that had previously completed a sheep flock health survey (Study 5), beef herd health survey (Study 4) or both. Sixty-nine farmers were contacted by their preferred form of contact, either telephone or email, and 35 agreed to participate in the study. The region and farm size are presented in Table 4 in Section 2.4.1.

3.3.2. Ethics

All farmers who agreed to participate in the study were asked to read an information sheet detailing what would happen during the study, what would be done with their information and their data protection rights. After reading this information sheet, farmers were asked to fill in a consent form. All farmers that participated in the study agreed to all parts of the consent form. Participation was voluntary. The information sheet and consent form can be found in Appendix 1.

The study was approved by the University of Nottingham School of Veterinary Medicine and Science Ethics Committee (no 1850 160916). The ethics form can be found in Appendix 2.

3.3.3. Study design

This study used a nested mixed methods design. The main design was the quantitative data collection and analysis to investigate differences between two antimicrobial data collection methods. A qualitative interview component was embedded into the study to examine farmers' experiences with the antimicrobial data collection over the study period.

3.3.4. Collection of AMU

Farms were visited three times between July 2018 and February 2020. On the first visit, farmers were given an empty 50 litre bin with instruction to place any empty antimicrobials used in sheep and beef cattle during the study period into the bin. The bin was labelled with example pictures of different types of antimicrobials (bottles, tubes and intra-mammary products). On the second visit, the contents of these bins were collected as well as a copy of their medicine records corresponding to the dates between the first and second visit. Farms were asked to continue to use the bins. The contents of the bins were collected for the final time on the third visit, as well as their medicine records corresponding to the date of the second visit date to the third visit date. The farmers were asked if there was anything missing from their farm records or the deposits in the bin and their answers were recorded. Farmers were also asked about the number of oral and parenteral antimicrobial treatments administered to new-born lambs.

The following data was recorded from the contents of the bins: drug name, drug concentration, number of millilitres/grams of antimicrobial, and number

of bottles/packages. For the medicine records, the following data was recorded: date, drug name, number of millilitres/grams of antimicrobials, number of animals (for records of group treatments), species, and reason for treatment. From this, the mass of active ingredient (mg) by antimicrobial class was calculated for each data collection method.

At the final visit the farmers were asked a short set of open-ended questions to understand their experience of taking part in the study. A copy of these questions is presented in Appendix 3. The aim was for the participants to self-evaluate their antimicrobial recording practices and their use of the antimicrobial bin. With the participants consent, the questions and answers were audio recorded.

3.3.5. Quantitative data analysis

All quantitative data analysis was conducted in Stata 16.1 (Stata SE/16.1, Stata Corp., College Station, TX, USA). The total measurement of antimicrobials in weight (mg) of active substance was quantified for the contents of the bins and the medicine records for each farm. Medicine records were investigated for missing data for date, product name, quantity used, number of animals, species, and reason for treatment.

The median and interquartile range of AMU by antimicrobial class was calculated for the medicine records and antimicrobial bins. Kendall's T_a correlation coefficients and the corresponding p-value were calculated per antimicrobial class to measure the strength of association between the medicine records and antimicrobial bins.

The total mg of antimicrobials from the medicine records was plotted against the total mg of antimicrobials from the antimicrobial bins with a line of equality at y=x. To compare the systematic variation of antimicrobial data collection methods, a Bland-Altman plot of the difference between the quantities of antimicrobial (mg) measured by the bins and the medicine records against the mean of the two measures was used (Giavarina, 2015). The Shapiro-Wilk W test revealed that the difference between the bins and medicine records were not normally distributed and an inspection of the histogram plot showed a left skewed distribution. Therefore, the limits of agreement that are usually calculated with the Bland-Altman plot should not be used for interpretation as this is based on the assumption that the differences between methods is normally distributed (Bland and Altman, 2010). The mean of the difference between the bins and medicine records represents the mean bias and was included as a horizontal line on the Bland-Altman plot. A horizontal line at y=0 was also included on the Bland-Altman plot as this represents the line of equality, which is where points would lie if both methods gave the same measurement.

To further understand the level of agreement between the bins and medicine records quantitatively, bias, discordance, and scale differentials were calculated using rank parameters of Kendall's T_a based on work by Newson (2006b) and Newson (2006a). Disagreement can be defined as:

$$\frac{E[(A-B)^2]}{2\sigma_A\sigma_B} = (1-\rho_{AB}) + \frac{(\mu_A-\mu_B)^2}{2\sigma_A\sigma_B} + \frac{(\sigma_A-\sigma_B)^2}{2\sigma_A\sigma_B}$$

Where (A_i, B_i) are sampled from a common bivariate distribution, μ_A and μ_B are means, σ_A and σ_B are standard deviations and ρ_{AB} is the correlation coefficient. The terms on the right hand side represent discordance, squared bias, and scaled differential from left to right.

Newson (2019) argues that discordance, bias, and scale differentials are measured better using rank parameters than regression parameters as they are less influenced by outlying data. Kendall's T_a gives confidence intervals and p-values for discordance, bias and scale differentials.

3.3.5.1. Discordance

Assume an indexed population of farms, with A and B as the quantity of antimicrobial in the bins and medicine records for each individual, respectively, and a sampling scheme for sampling pairs of individuals (indexed as i and j) at random from that population (Newson, 2019).

Kendall's T_a of A and B can be defined as:

$$\tau(A,B) = E[sign(A_i - A_j)sign(B_i - B_j)]$$

where E(·) denotes expectation, and sign(x) is 1 if x > 0, -1 if x < 0, and 0 if x = 0.

If the indexed population is a population of farms, and (A_i, B_i) is the quantity of antimicrobials measured by the bins and medicine records respectively, then T(A, B) is the difference between the probability that the measurements agree and the probability that the measurements disagree, assuming that they are given two different farms at random and choose which one uses more antimicrobials. Concordance and discordance for probabilities like Kendall's T_a lie on a scale between -1 and 1, where -1 is a perfect negative relationship, 0 is no overall ordinal relationship and 1 is a perfect positive relationship (Newson, 2002).

3.3.5.2. Bias

For normally distributed data, bias can be measured by calculating the mean differences between A_i and B_i using paired t-tests. Instead, for this non-parametric method, bias was investigated by calculating the percentile differences between A_i and B_i (Newson, 2019). Confidence intervals for the percentiles were calculated by using Fisher's z transform on the mean signs of the differences between data values and percentiles. The percentiles with

confidence intervals were plotted against the corresponding percentages. By plotting percentiles we can see the median difference and identify any exceptional positive or negative differences.

The mean sign is also known as a sign test statistic (Newson, 2006b). The null hypothesis is that the median of the differences is zero. The mean sign is the difference between the probabilities $Pr(A_i>B_i)$ and $Pr(A_i<B_i)$, i.e. the difference of the probability that the bins measured more antimicrobials than the medicine records and that the medicine records measured more than the bins. It can be denoted as:

$$E[sign(A_i - B_i)]$$

The mean sign of the difference between bins and medicine records was calculated to identify how much more likely or unlikely the bins give larger measurements than then medicine records.

3.3.5.3. Scale differentials

Scale differentials refers to whether the measurements of one method had greater differences between the lowest and highest measurements compared to the other method. This can be measured by Kendall's T_A between the mean AMU ((bins-medicine records)/2) and the differences in AMU (bins-medicine records). This can be estimated with rank parameters as:

$$\tau\left[A - B, \frac{A + B}{2}\right] = \tau(A - B, A + B)$$

A positive T[A-B,(A+B)] means that a random pair of A_i usually differ by more than the corresponding B_i. The proof of these calculations can be found in Newson (2019).

3.3.6. Qualitative data analysis

Qualitative content analysis was carried out to identify the advantages and problems faced by farmers when using the bins and medicine records over the study period. The process was partly deductive because it was known that data would be categorised into the benefits and barriers of each method. The analysis was also partly inductive as it was not known what these benefits and barriers would be and therefore a coding scheme was not used a priori. The transcripts were read multiple times and meaningful text that captured key thoughts and concepts were coded. These codes were developed into categories, which were then organised into the benefits and barriers to each method (Hsieh and Shannon, 2005). The coding process was facilitated by NVivo (NVivo qualitative data analysis Software; QSR International Pty Ltd. Version 12, 2018).

3.3.7. Integration of quantitative and qualitative data

The purpose of using the qualitative data was to help to explain any findings from the quantitative data. To integrate the data, results were presented in a

table with the potential outcomes of convergence, complementarity, expansion and divergence (Fetters and Molina-Azorin, 2019, Morgan, 2019)

3.4. Results

There were thirty farms that adhered to the bin and medicine record keeping over the study period (Figure 5). Between visits one and two, records were not available for two farms as they did not record their medicine use. One farm did not adhere to the use of the antimicrobial bin and one farm accidently threw the contents on the bin away. Between visits two and three, records were not available for two farms as they did not record their medicine use and two further farms lost their AMU records due to computer issues. The final thirty farms consisted of three sheep-only farms, seven beef-only farms and twenty mixed-species farms.

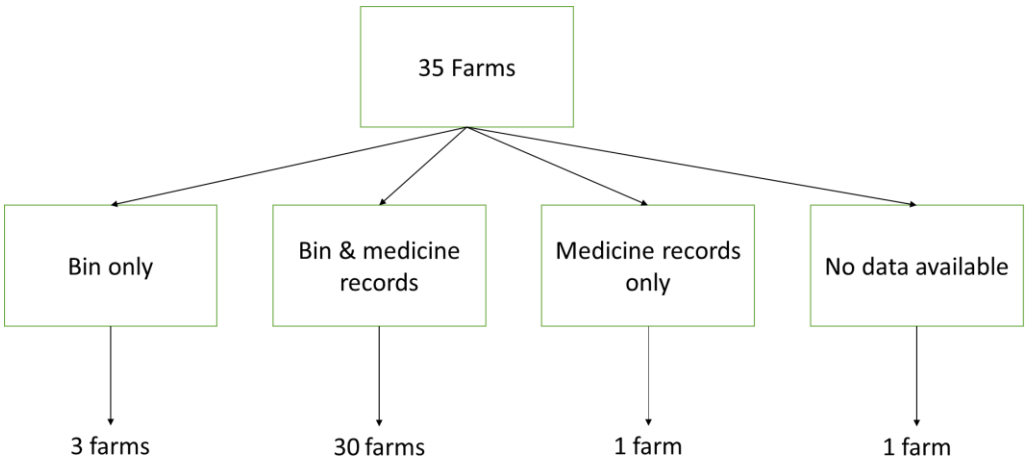


Figure 5: Adherence of 35 farmers to the antimicrobial record keeping and use of the antimicrobial bin over the study period

3.4.1. Quantitative evaluation

Upon inspection of farmers medicine records, 25/30 (83%) of farms recorded group antimicrobial treatments without recording individual ear tags numbers at some point in the study period. Of the 20 mixed-species farms, 13 (65%) clearly indicated the species antimicrobial products were used in. Of the 23 farms with sheep, 18 used antimicrobials in new-born lambs without recording this information, with a median of 32.5 missing treatments per farm (IQR=18-130).

Out of a total 1433 antimicrobial record entries, 11 (0.8%) were missing the quantity of AMU, 103 (7%) were missing the number of animals treated, 301 (21%) were missing the reason for treatment, and 11 (0.8%) were missing the date of treatment. Of the 807 antimicrobial records from mixed-species farms, 227 (28%) were missing the species the antimicrobial was used in.

3.4.1.1. Comparison of bins and medicine records

The median total mg of antimicrobials used on the thirty farms based on the medicine records was 317,617 mg, compared with 458,500 mg based on the antimicrobial bins (Table 5).

Table 5: Median AMU and Kendall's T_a correlation by antimicrobial class on thirty farms based on medicine records and antimicrobial bins

Antimicrobial	Medicine records			Antimicrobial bins			T_a (P-value)
	N farms	Median (mg)	IQR (mg)	N farms	Median (mg)	IQR (mg)	
Tetracycline	28	75,750	27,100-449800	26	234,000	60,000-560,000	0.68 (<0.01)
Penicillins	29	51,700	20,000-102,600	28	82,500	40,000-205,000	0.68 (<0.01)
Aminoglycosides	15	53,500	26,250-105,750	21	50,000	25,000-100,000	0.51 (<0.01)
Macrolides	14	10,647.5	4,875-27,700	13	25,000	17,000-41,700	0.38 (<0.01)
Phenicols	4			5			
Sulphonamides	3			4			
Fluoroquinolones	1			2			
Cephalosporins	1			3			
Total	30	317,613	97,675-605,650	30	458,500	129,000-882,000	0.62 (<0.01)

The mean average difference between the bin and medicine records measurements was 145,662 mg (CI=17,881, 273,442), indicating that on average the bins measured 145,662 mg more active ingredient of antimicrobials than the medicine records. A scatterplot to demonstrate the correlation between the two methods is presented in Figure 6.

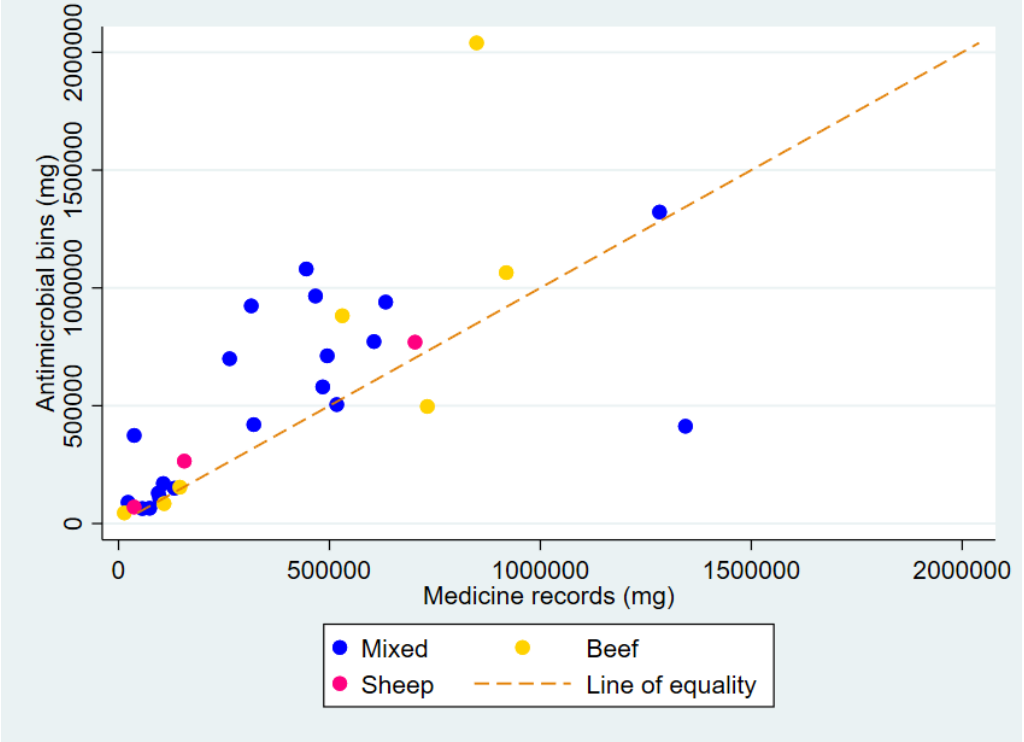


Figure 6: Scatterplot and line of equality of AMU (mg) measured by bins and medicine records for 30 sheep and beef farms

Inspection on a Bland-Altman graph (Figure 7) suggested that this bias was due to farms that use larger quantities of antimicrobials, whereas farms that use smaller quantities of antimicrobials were closer to zero (the line of equality). There were two outlying farms, one of which had more antimicrobials recorded in the bins than their records, and the other vice versa.

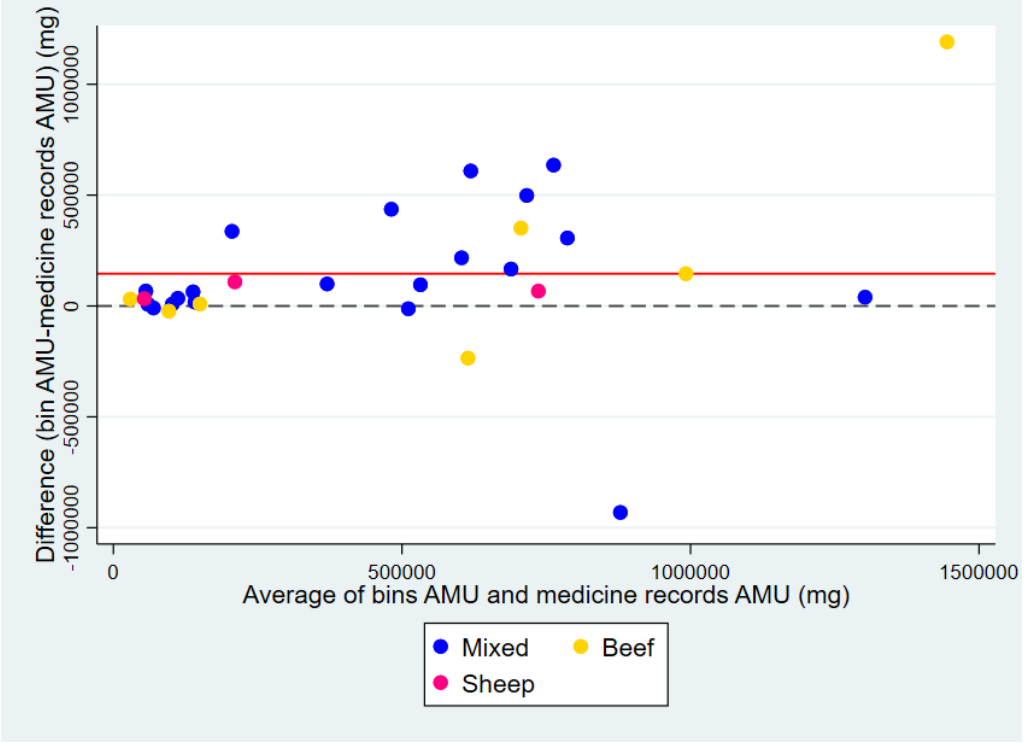


Figure 7: Bland-Altman plot to compare quantities of antimicrobials measured by the bins and medicine records for 30 sheep and beef farms. The red line represents the mean difference and the dashed line represents the line of equality.

3.4.1.2. Discordance

Kendall's T_a between the bins and medicine records was 0.62 (CI=0.39-0.78, p=<0.001). This indicated that the bin and medicine record measurements were 39-78% more likely to agree than disagree when asked to rank two random farms as to which used more antimicrobials.

3.4.1.3. Bias

The mean sign of the difference between the bins and the medicine records was 0.67 (CI=0.29-0.87, p=0.003), indicating that the bins were 29-87% more likely to measure more AMU than the medicine records, given one random farm to measure from the population.

Figure 8 presents the percentile differences between the two measurement methods. They show that most of the time the bin measured more antimicrobials than the medicine records. The confidence interval becomes larger as the percentile increases. The confidence interval was also larger when the medicine records measured more than the bin.

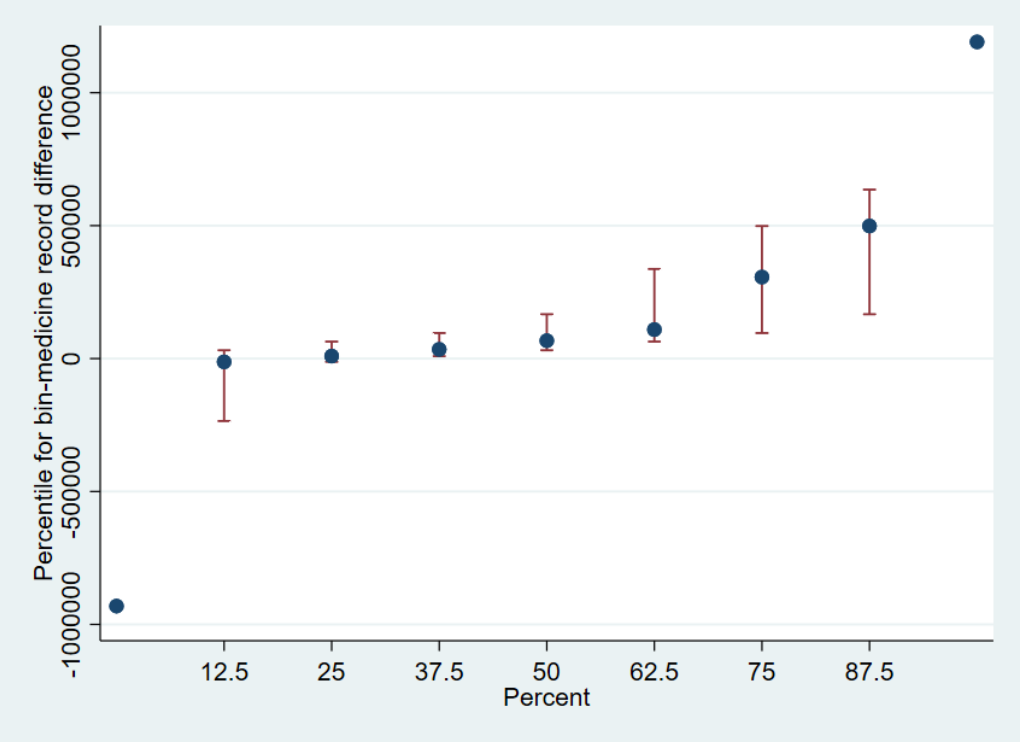


Figure 8: Percentile differences between the quantities (mg) of antimicrobials measured from the bin and medicine records for the same farm

3.4.1.4. Scale differential

Kendall's T_a between the mean AMU and the difference between bin and medicine record AMU was 0.33 (CI=0.06-0.56, P=0.02). This indicated that if two farms were chosen at random, it was 6-56% more likely that the difference between the lower using farm and the higher using farm will be greater according to the bins than according to the medicine records than that this difference will be greater according to medicine records than according to the bins. This means that the scale of variability between bins was larger than the scale of variability between the medicine records.

3.4.2. Qualitative evaluation

3.4.2.1. Farmers evaluation of the antimicrobial bin

3.4.2.1.1. Benefits of the antimicrobial bin

For most farmers, the antimicrobial bin was easy to use.

> *"Yeh, well that's simple…all the empty bottles have gone in the bin and that's been no problem."* Farmer 19

> *"Yeh, that's been dead easy. As we use the antimicrobial we just put it in the bin. Dead easy. No problem at all."* Farmer 1

There appeared to be good adherence to the bin method because it was a simple process for farmers to follow. Many farmers thought that the contents of their antimicrobial bin was accurate:

"As far as I'm aware you've had everything that's come in." Farmer 13

"I don't think I've forgotten to chuck any bottles in there." Farmer 22

3.4.2.1.2. Barriers towards use of antimicrobial bin

However, farmers encountered some issues which would affect the reliability of using the contents of the bins for antimicrobial quantification. Notably, many farmers had part-used bottles and so these did not get deposited into the bin. Table 6 describes the multiple barriers to using the antimicrobial bin experienced by farmers over the study period.

Table 6: Barriers to using the antimicrobial bin experienced by famers in the study

Barrier	Description	Example quote
Bottles still in use	Some farmers used very little antimicrobials and did not use a whole bottle of antimicrobials.	*"Obviously there's part used bottles still in my medicine cabinet."* Farmer 33 *"I think there's maybe, like I say, there's maybe a bottle missing but it's probably still in use if you know what I mean."* Farmer 26
Multiple workers on farm	The farmers sometimes had other workers or students on the farm which made it difficult to keep track on if or where the empty bottles were being deposited.	*"I tend to put it in the bin but unfortunately there's my dad and some workmen and some of it disappears [laughter] into different bins"* Farmer 18 *"Yes, well, what I've put in it is what I've used for the sheep but the students could have put other bottles into another bin."* Farmer 10
Veterinarians administered treatments	Sometimes the farmers' veterinarian would administer the antimicrobial treatment and take the antimicrobial packaging so it would not be deposited in the bin.	*"There is certain treatments that are in the book that won't be in the bin that will have been administered by the vet."* Farmer 6 *"The only drugs which would have been drugs that were administered to cattle and I think to one ewe that was taken to the vets. They're what the vets actually administered so you wouldn't have had empty containers for that."* Farmer 13
Practicality in the field	One farmer mentioned that the antimicrobial packaging would not be deposited into the bin if opened and used in the field. They commented that a smaller bin size may be more practical.	"*When we're out in the field and open boxes up and not enough of them made it back to the bin but that's where we would have been better to have a smaller box maybe?*" Farmer 2
Location of bin	One farmer said that the location of the bin was detrimental to adherence to the study.	*"The box – it worked and maybe we just probably needed a better spot…Better siting of our box - that's all our side."* Farmer 2

3.4.2.2. Farmers' evaluation of medicine recording

3.4.2.2.1. Benefits of medicine recording

Some farmers pointed out that recording their medicine use over the study period was easy as they have to do it by law and for farm assurance schemes anyway.

> *"Well, just the same thing that I've always done sort of thing"* Farmer 23

> *"Well I suppose we do, do it anyway for the Red Tractor*" Farmer 7

Some farmers may not have kept useful medicine records before the study began. However, they noted that keeping more comprehensive medicine records over the study period let them reflect on their AMU and identify potential problem areas.

> *"It's a lot better now than it was to start with. A lot more conscientious and it's quite satisfying to do it and keep it up to date*" Farmer 25

> *"I suppose it pin points, even though you've bought a bottle of antimicrobial, it pin points on what animals have been treated and why."* Farmer 7

Some farmers thought that their medicine records were completely reliable:

> *"Yeh, they're reliable as they always are. Which is, you know, we inject them and then we write it down so it's bang on yeh."* Farmer 8

The majority of farmers thought that their medicine recording was fairly reliable, with potentially a few missing treatments. They often cited their reliability in percentages, which commonly ranged from 90-98%:

> *"I haven't recorded the lambs with joint ill, apart from that, I would say our recording was probably 98%"* Farmer 31

> *"Yes, I would have recorded nearly all of it but I obviously might have missed the odd one but I'm just simple... So I would say… I don't know ninety odd percent, ninety-five percent reliable I would say."* Farmer 21

Most farmers said that their antimicrobial recording was reliable for their beef cattle. Cattle were usually given treatments on an individual basis and due to their large size, have to be restrained safely. This means that it was easy to identify the cattle and a medicine book was at hand to record the treatment straight away.

> *"Yeh, but the cattle would be good because they're in a crush and held there and you can read the tags easier and stuff, yeh."* Farmer 32

> *"I write down when I'm at the cattle crush what I'm treating every animal. Whether its wormers or antimicrobials it's all put in the book*

and then I transfer it out of my book and into the computer. So it's 100% accurate. I know exactly what everything's had." Farmer 19

3.4.2.2.2. Barriers towards medicine recording

The barriers to antimicrobial recording were centred on AMU in sheep rather than beef cattle. Farmers admitted that their antimicrobial recording for sheep was not at the same standard as for their beef cattle. This had a lot to do with the differences in the way in which antimicrobials were administered to the two species. With the sheep, there were two contexts that made antimicrobial recording difficult. Firstly, at lambing time where farmers were busy, multiple people were working on farm, lambs were not identifiable and multiple treatments may be given. Secondly, treatments were given to sheep when out in the field which made immediate antimicrobial recording impractical and farmers may forget to record later on. Table 7 describes the multiple barriers to antimicrobial recording experiences by farmers over the study period.

Table 7: Barriers to antimicrobial recording experienced by farmers taking part in the study

Barrier	Description	Example quote
Busy lambing period	Lambing was a particularly busy period for farmers which meant that antimicrobial recording was not prioritised.	"*The sheep, especially in lambing time, there are periods where we so busy that maybe the paper work or record keeping wasn't the main priority*." Farmer 11 "*You're flat out busy so sometimes with the sheep you don't record it as well as we should*." Farmer 32
Forgetfulness	Some farmers said they forgot to write treatments down when they did not have their medicine book readily available.	*"And some of our foot treatments, like if you've got the sheep in pens and you see a couple of lame ones and treat them and then go off and do something else, it could easily get forgotten to go back and put it in the medicine book later on because the medicine book is always in the office."* Farmer 4 *"You forget that you've done some or you write it down and forget to put it down"* Farmer 3
Multiple workers on farm	Sometimes there were multiple workers on the farm which meant it was difficult to keep track of antimicrobial recording.	*"Lambing time is the one where it's difficult because there's several different people administering drugs*." Farmer 17 *"Like when we're lambing you write it down or somebody else will write it down and there's so many people doing different things and then it gets missed*." Farmer 3
No identification of lambs	Some farmers did not tag their lambs until they are older and so there was no formal way of identifying young lambs when recording antimicrobial treatments.	"*We don't tag the lambs or mark them until they go out so we wouldn't be able to record exactly which lamb had what from that point of view."* Farmer 13 *"With the baby lambs there's not much identification to each animal so there's only so much you can record but we monitor how much we're using."* Farmer 2
Practicality in field	Antimicrobials were sometimes administered to sheep in the field where the weather conditions can make it impractical to carry out antimicrobial recording.	*"We wouldn't be as recording sheep just because, you know, if you've caught something outside in the field and it's heaving it down with rain you don't tend to get your phone out to try and find them because half the time if the bottle's in your pocket the batch numbers rubbed off and you're not sure which it is."* Farmer 32 "*About 50% because some of the sheep when you're lambing I was writing it down on a piece of paper and it got washed and got soaking wet so it's about 50% right with the sheep*." Farmer 3

Time lag in recording	Some antimicrobial recording was carried out in batches and therefore AMU could not be attributed to a single animal or a single day.	*"Generally with the sheep medicines it's done on a monthly basis … So a rough date but that's as close as it gets really."* Farmer 18 "*Well lambing time for sure because I do tend to record what I've used at the end of lambing and just attribute it to lambing."* Farmer 6

3.4.3. Integration of results

To integrate and report the results of the qualitative and quantitative analysis, a cross tabulation of results is presented in Table 8.

Table 8: Assessment and integration of qualitative and quantitative results for the evaluation of bins and medicine records as methods of quantification of antimicrobials

	Convergent results	**Complementarity qualitative results**	**Complementarity quantitative results**	**Expansion results**	**Divergent results**
Qualitative results	A) Barriers to medicine recording meant farmers were likely to record less than their actual AMU. B) Farmers found it hard to keep track of medicine recording during lambing time.	Bins may be missing a few bottles so may under represent actual AMU.		Only completely empty bottles were deposited into the bin.	Farmers thought that their bins and medicine records were fairly reliable.
Quantitative results	A) Bins were significantly more likely to measure more AMU than medicine records. B) 18 farmers used antimicrobials in new-born lambs without recording this information.		Bias increased as total mg of antimicrobials increased.	Bins were significantly more discriminating than medicine records.	Bins were more significantly likely to measure more AMU than medicine records.

3.5. Discussion

In the present study, the use of medicine records was evaluated against antimicrobial bins as a method to quantify antimicrobials on sheep, beef, and mixed species farms. It was identified that the antimicrobial bins were significantly more likely to measure more AMU than the medicine records. These findings are similar to those of dairy farms (Nobrega et al., 2017, Pucken et al., 2021). Unlike the other studies, this study also used qualitative methods to further understand the results from the quantitative evaluation. The qualitative analysis suggested that the antimicrobial bins may under-represent actual AMU because of part-used bottles, treatments administered by the veterinarian, and losing track of multiple workers on the farm. This implies that if antimicrobial bins under-represent AMU, then medicine records under-represent actual AMU even more so. Furthermore, farmers stated that their record keeping over the study period was better than their usual recording. Therefore, at present, on-farm medicine records may not reflect actual on-farm AMU and should be used with caution, especially if retrospective data is taken.

The qualitative analysis indicated that many farmers thought that their medicine recording and deposits into the antimicrobial bin were a fairly accurate or completely accurate representation of their AMU. If this was the case, then the difference between the quantities in the bin and the medicine records would be zero. The Bland-Altman plot showed there was a bias towards measuring more antimicrobials in the bin than the medicine records (Giavarina, 2015), and the mean sign test confirmed that the bins were 29-87% more likely to measure more AMU than the medicine records, which is in agreement with findings of dairy farms (Nobrega et al., 2017, Antillón et al., 2020, Pucken et al., 2021). Additionally, the medicine records and bins were likely to be concordant only 39-78% of the time. This suggests that farmers self-report of the accuracy of their recording may not be consistent with actual accuracy.

Farmers mentioned many barriers towards keeping accurate medicine records. This appeared to be a particular problem for sheep records due to contextual issues such as administration of treatments in the field and lack of identification of lambs. The quantitative evaluation, correspondingly, showed that two thirds of sheep farmers did not record their AMU in lambs. This may contribute as to why the antimicrobial bins tended to contain more antimicrobials than the medicine records. Poor record keeping of antimicrobial treatments given to new-born lambs may also explain why more farms recorded aminoglycoside use in the antimicrobial bins compared with the medicine records. The two oral antimicrobials licensed for use in lambs in the UK are aminoglycosides. It is therefore suggested that researchers attempting to quantify AMU on sheep farms should ask separate questions on antimicrobials used in new-born lambs, otherwise this data may be missed.

Although most farmers found the antimicrobial bin simple to use, they also mentioned some barriers to their use. Notably, if antimicrobial bottles were still in use, then this bottle would not be deposited in the bin. Another issue was if there were multiple workers on the farm it was hard for the farmer to control where the empty medicine bottles ended up. This may offer an explanation as to why the scale of variability was larger for the antimicrobial bins than the medicine records. One missing bottle of antimicrobials in the bin could represent a difference of thousands of milligrams of active ingredient, whereas medicine records provided a more detailed account of AMU. Indeed, this was one of the advantages of medicine records identified by farmers. The detailed record keeping and inability to deposit half-used antimicrobial packages into the bin may also explain the greater number of farms recording treatments with tetracyclines and penicillins in their medicine books compared with the antimicrobial bins.

The median antimicrobial use was much higher in the antimicrobial bins compared with the medicine records for tetracyclines and macrolides in particular. Some farmers gave parenteral antimicrobials to new-born lambs rather that oral antimicrobials, which are likely to be tetracyclines as they are a first line antimicrobial (EMA, 2019). Parenteral antimicrobial treatments given to lambs were unlikely to be recorded in the medicine books. This study was unable to specifically explain the large difference in macrolide use between the two measurement methods, and this requires further investigation.

The Bland-Altman plot and percentile plot indicated that bias between the data collection methods increased as the amount of antimicrobials increased. It is possible that farmers could lose track of their medicine recording if their AMU was high. For example, farmers said that they would forget to write treatments down, especially during busy periods of higher AMU such as lambing. When there were multiple workers on the farm, farmers found it difficult to keep track of what antimicrobials were deposited into the bin or recorded in the medicine book, suggesting there would be more errors in the data collection methods. The associations between the number of workers on the farm and differences in data collection methods were not investigated in this study, but it could warrant further research. The confidence intervals of the percentile plots was also larger when the medicine records measured more antimicrobials than the bin. This might relate to instances where farmers and other workers on the farm forgot to place antimicrobial packaging into the bin.

On-farm medicine records are required to quantify AMU on mixed-species farms as other methods, such as veterinary sales data or the antimicrobial bins, cannot specify which species an antimicrobial was used in. However, over a quarter of records from mixed-species farms in this study were missing

the indication for species. This makes it extremely difficult to accurately calculate on-farm AMU, as many units of quantification take into account the weight of the animals at risk (Mills et al., 2018). It is therefore important that the electronic medicines hub that is currently under development for sheep and cattle in the UK includes a mandatory column for the indication of species (AHDB, 2020a). Because species was missing for many records in this study, the AMU could not be quantified using specific antimicrobial units such as animal daily doses. Consequently, total weight of antimicrobial active ingredient was used to compare the two methods of data collection. This was a limitation because it was not possible to account for the treatment doses or number of animals at risk on each farm. However, it was still possible to evaluate medicine recording against the antimicrobial bins by looking at the difference in quantities of antimicrobials in milligrams.

Another issue with farmers' medicine recording was that the identity of the animal was not always recorded. The majority of farmers recorded a group treatment at least once during the study period. Sometimes large quantities of antimicrobials were recorded without specifying the number of animals this was administered to. The qualitative findings suggest that this might happen because farmers may fill in their medicine records retrospectively and therefore cannot attribute antimicrobials to a single animal on a single day. Additionally, farmers may administer antimicrobials to a group of animals in the field where they may be unable to identify individual animals. In the UK, sheep must have an electronic identifier, which would make it easy for farmers to identify animals if they use a reader (DEFRA, 2014). However, few farmers have adopted electronic identifier tools for recording information (Lima et al., 2018, Kaler and Ruston, 2019). Greater adoption of electronic identifier tools might help to improve medicine recording by sheep farmers.

The quantities of antimicrobials administered to animals was well-recorded by farmers in this study, with only 0.8% missing entries. This is in contrast with studies of dairy farms in Canada and Switzerland, where over half of treatment records had missing entries for dose (Nobrega et al., 2017, Pucken et al., 2021). The difference could be because of differences in the type of AMU on dairy farms compared with sheep and beef farms. The main reason for antimicrobial treatments on dairy farms appears to be mastitis and therefore intramammary antimicrobials are the most common (Higham et al., 2018). Furthermore, the study by Pucken et al. (2021) only investigated treatments for mastitis. Whereas, injectable antimicrobials are common on sheep and beef farms for problems such as lameness and pneumonia, and mastitis tend to be rarer (Davies et al., 2017, Doidge et al., 2020b).

3.5.1. Limitations

This study compares antimicrobial quantities by weight of active ingredient. This does not take into account the number or weight of animals on the farm.

More complete recording of animal species on mixed farms is required to measure AMU using units that take into account the number and weight of animals, as sheep and cattle would have separate units.

The study used a convenience sample of sheep and beef farmers who were likely to be more interested in AMU. Therefore, the study could suffer from selection bias and the sample may not be representative of sheep and beef farms in England and Wales. Only a small number of farms were single species. Medicine recording by farmers during the study may not represent how they record medicine use when not taking part in the study as participants stated that their recording was better over the study period. The study sample was small and this might contribute to the large confidence intervals calculated in the quantitative analysis, including the large variability in bias, scale and concordance. The large variance in bias, scale, and concordance may also be due to the multiple barriers towards medicine recording and use of the bins identified in this study; certain barriers may only effect certain farmers. A small sample size was required for an in-depth investigation into on-farm AMU recording.

Both methods of data collection have their own bias and therefore neither can be used as a gold standard to compare to. However, the use of qualitative methods along with the quantitative methods allowed for an understanding of what the bias was with each method.

3.6. Conclusions, research and industry implications

The results of this study demonstrate that medicine records may under-represent actual AMU on sheep and beef farms, whereas measurement using antimicrobial bins may be biased due to part-used bottles and veterinarian administered treatments not being included. Medicine records and antimicrobial bins may not be used interchangeably as methods for measuring AMU. Missing data on species and group treatments made it difficult to quantify AMU on mixed species farms. Farmers found it particularly hard to keep records during lambing time and when antimicrobials were administered in the field. The findings from this study provide some recommendations on how antimicrobial quantification from treatment records can be improved. Firstly, researchers or industry should ensure that there is a mandatory field within the treatment records to indicate the species the antimicrobial was used in for mixed species farms. Secondly, the use of electronic identifiers should be encouraged to make it easier to record treatments in the field. Finally, there should be separate sections regarding antimicrobials administered to new-born lambs as these are often not included in medicine records. These recommendations should make quantification of antimicrobials on sheep, beef, and mixed species farms more feasible.

3.7. Impact of Covid-19

The use of a denominator for AMU calculations is important to take into account the number and weight of animals on the farm. One of the original aims of this study was to calculate AMU using multiple AMU metrics. For beef farms in particular, there will be considerable movement of animals on and off the farm within a year period and it has been recommended that the weight of AMU is interpreted relative to the average live-weight of animal population (CHAWG, 2019). The data for the number of cattle on farm, movements of cattle on and off the farm, and cattle deaths were meant to be obtained from the British Cattle Movements Service (BCMS), who maintain an online database of all bovine animals in Great Britain called the Cattle Tracing System (CTS). However, the Covid-19 pandemic has severely affected the running of the BCMS and requests are backlogged by over six months. This means the cattle movement data was not available before the submission of this thesis. The hope is to develop this study further by including additional metrics for comparison when the movement data becomes available.

4. Study 2: AMR patterns on sheep and beef farms in England and Wales: A comparison of disk diffusion interpretation methods

This chapter has been published in a peer-reviewed journal:

Doidge, C., West, H., & Kaler, J. (2021). Antimicrobial Resistance Patterns of Escherichia coli Isolated from Sheep and Beef Farms in England and Wales: A Comparison of Disk Diffusion Interpretation Methods. *Antibiotics*, 10(4), 453.

Author contributions:

All author's contributed to conceptualisation, project administration and methodology. CD had roles in formal analysis, investigation, data curation, writing (original draft) and visualisation. JK and HW had resource, supervision and writing (review and editing) roles. JK attained funding for the study.

4.1. Abstract

Little data exists on the levels of AMR from bacteria isolated from healthy sheep and beef cattle in the UK. The aim of this study was to investigate AMR patterns on sheep and beef farms in England and Wales using multiple interpretation methods. Faecal samples (n=350) from sheep and beef cattle were collected from 35 farms in 2019. Antimicrobial susceptibility testing against ten antimicrobials was carried out for 1115 (699 sheep, 416 beef) presumptive *Escherichia coli* isolates using the disk diffusion method. Susceptibility was interpreted using clinical breakpoints, which determine clinically resistant bacteria, and epidemiological cut-off values and livestock-specific cut-off values, which determine microbiological resistant bacteria (non-wild type). Cluster analysis was performed to identify patterns in AMR. A high frequency of wild type for all ten antimicrobials was observed in isolates from sheep (90%) and beef cattle (85%). Interpretation of susceptibility using livestock-specific cut-off values showed a cluster of isolates that were non-wild type to cefotaxime and amoxicillin/clavulanic acid; whereas, clinical breakpoints did not. A multivariable multilevel logistic regression model was built to determine drivers of tetracycline non-wild type isolates. The use of tetracyclines on farm (P=0.025) and the copper concentration in the soil (P=0.033) were significantly associated with tetracycline non-wild type isolates. The results suggest that using human clinical breakpoints could lead to the under-reporting and over-reporting of AMR in sheep and beef cattle.

4.2. Introduction

The administration of antimicrobials leads to the selection of antimicrobial resistant bacteria and food-producing animals are one of several potential

sources of AMR (Marshall and Levy, 2011). Although AMU is thought to be low in sheep and beef cattle (Davies et al., 2017, Doidge et al., 2020b), the large numbers of sheep and cattle in the UK may potentially contribute to the dissemination of antimicrobial resistant bacteria (DEFRA, 2019b, Welsh Government, 2019). National surveillance of AMR from bacteria isolated from sheep and beef cattle only uses samples that are submitted for clinical diagnostics (VMD, 2020b). The use of clinical isolates suggests that AMR to commonly used antimicrobials, such as tetracycline and ampicillin, is relatively high in sheep and cattle (Hennessey et al., 2020). However, clinical samples are potentially biased as they usually come from sick animals which may have been treated with antimicrobials. At present in the UK, active national surveillance of healthy sheep or cattle does not exist.

There are few studies investigating antimicrobial susceptibility of organisms isolated from healthy sheep and beef cattle in the UK. These studies suggest that AMR on sheep and beef farms is relatively uncommon (Vali et al., 2007, Enne et al., 2008, Silva et al., 2020), although ESBL positive beef farms may be increasing (Snow et al., 2011, Velasova et al., 2019). Examining the presence of ESBL *E. coli* has been the focus of more recent studies on beef farms (Snow et al., 2011, Velasova et al., 2019). Therefore, other resistance types may have been missed in these studies. Other studies have investigated a larger range of AMRs, but only investigated a few farms (Vali et al., 2007, Silva et al., 2020). Hence, variance between farms with respect to AMR patterns were not investigated. More information regarding AMR on sheep and beef farms in the UK is required. Indeed, a systematic review of AMR on British sheep and cattle farms called for additional efforts in collecting farm level AMR data (Hennessey et al., 2020).

Previously identified factors associated with AMR in food-producing animals include the use of antimicrobials, either as therapeutics to treat sick animals, or as growth promoters (Varga et al., 2009, Bosman et al., 2014, Gibbons et al., 2016). The number of animals on the farm, region of farm, and type of animals sampled have also been reported as factors associated with AMR in bacteria isolated from animals (Berge et al., 2010, Mainda et al., 2015). It has been shown that bacterial isolates of animal origin may present with resistance even when the animals have not been exposed to antimicrobials (Mir et al., 2016, Mir et al., 2018). Markland et al. (2019) illustrate that when cefotaxime-resistant bacteria were present in samples from beef cattle, resistant bacteria were more abundant in soil samples. This indicated that the environment, such as soils and forage, may be a natural source of antimicrobial resistant bacteria for food-producing animals (Markland et al., 2019). However, the factors that affect the prevalence of antimicrobial resistant bacteria in soils is unclear (Lee et al., 2020). One potential explanation is that heavy metals like copper and zinc may co-select for AMR in

soil. The effect of metal concentrations in soil on the prevalence of AMR in farm animals requires further investigation.

Disk diffusion testing is a commonly used phenotypic method for determining antimicrobial susceptibility. As discussed in Section 2.2.4, scientists can interpret the results of disk diffusion tests using clinical breakpoints, ECOFF values or tailor-made cut-off values using the NRI method. Both clinical breakpoints and ECOFF values are mainly relevant to human medicine. Research suggests that using human clinical breakpoints to interpret veterinary data may lead to calculating a higher AMR prevalence than actually occurs (Silva et al., 2020). Additionally, the peak of susceptibility for isolates of animal origin may differ from the peak of susceptibility for human isolates (Dias et al., 2015, Silva et al., 2020).

The NRI method has been used to investigate the susceptibility of organisms of animal origin when EUCAST or CLSI breakpoints do not exist (Pereira et al., 2014, Lim et al., 2016). Furthermore, the NRI method has been used when clinical breakpoints or ECOFF values do not appear appropriate (Dias et al., 2015, Silva et al., 2020). It may be useful to interpret the inhibitory zone diameters of isolates of animal origin using clinical breakpoints, ECOFF values, and the NRI method so that comparisons can be made and the appropriate cut-off values can be chosen.

A previous study based on isolates from four sheep farms compared these three interpretation methods and suggested that sheep-specific cut-off values were most fitting (Silva et al., 2020). There needs to be additional studies with a larger number of participating farms to confirm these results, and similar studies have not been carried out for other livestock species. Additionally, the implications in terms of interpretation of AMR patterns requires further investigation. Therefore, the aim of this study was to investigate and compare AMR patterns on thirty-five sheep and beef farms in England and Wales using multiple interpretation methods. Further objectives were to identify clusters of AMR and to identify factors that were associated with AMR on sheep and beef farms. Based on previous literature, it was hypothesised that (1) previous AMU was associated with AMR and (2) environmental factors were associated with AMR.

4.3. Materials and Methods

4.3.1. Participant recruitment

Farmers identified for participation in the study were those that had previously completed a sheep flock health survey, beef herd health survey or both. Those that indicated that they would be interested in sharing their AMU data in the survey were contacted by their preferred form of contact, either telephone or email. Farmers were contacted in order of preference until thirty-five farms were recruited (see Section 2.4.1 for farm region and size).

4.3.2. Ethics

All farmers read an information sheet and signed a consent form before participating in this study. Participation was voluntary. Please see Appendix 1 for a copy of the information sheet and consent form.

The study was approved by the University of Nottingham School of Veterinary Medicine and Science Ethics Committee (no 1850 160916) (Appendix 2).

4.3.3. Sample collection

Each farm was visited between February and October 2019. Ten faecal samples from either sheep or beef cattle were taken at each farm. Random samples of fresh faeces were taken from the field or pen floor and each placed into a sterile bag. Location of sample collection was not the same for each farm due to the different production systems. Therefore, sample collection location was recorded (e.g. indoor pen or outdoor pastureland). Farmers were asked if they thought any of the animals in the field/pen had been given antimicrobials in the past two weeks. The samples were kept cool and were processed within 24 hours at laboratories at the University of Nottingham.

4.3.4. Isolation of *Escherichia coli*

For each sample, 2g of faeces were weighed and suspended in 18mL of Maximum Recovery Diluent (MRD) (Oxoid). Samples were serially diluted and 200µL aliquots were plated onto Tryptone Bile X-glucuronide (TBX) agar (Oxoid) for the detection of *E. coli. E. coli* form blue colonies on these plates while other Enterobacteriaceae form white colonies. TBX plates were incubated at 35°C for 24 hours. For each sample, the number of colonies with a typical *E. coli* phenotype were counted. The plate with between 30 and 300 colonies was chosen and six blue colonies from each plate was picked for streak plating. Single colonies were streaked onto Luria-Bertani (LB) agar (Lennox) and incubated at 35°C for 24 hours. From each plate, a single colony was put into a Microbank (Pro-Lab Diagnotics UK) and placed in a -80°C freezer. No further confirmatory testing was carried out so the isolates were considered presumptive *E. coli* isolates. All samples were positive for *E. coli* apart from five samples from farm 12. Four samples from farm 14 were lost during storage.

4.3.5. Antimicrobial susceptibility testing

At least three isolates from each sample were chosen for antimicrobial susceptibility testing. Antimicrobial susceptibility testing was undertaken following the EUCAST guidelines (EUCAST, 2020b). Isolates were resurrected from the Microbanks by streaking a bead across LB agar. Plates were incubated at 35°C for 24 hours. AMR testing was carried out for ten antimicrobials using the disk diffusion method. Colonies were suspended in MRD until it reached 0.5 McFarland standard. The dilution was then streaked across a Muller Hinton Agar plate (Oxoid) and the 10 antimicrobial disks were

placed onto the surface of the agar. The plates were incubated for 24 hours at 35°C. The zone diameters were then recorded using the EUCAST guidelines where possible (EUCAST, 2020a). For antimicrobials that do not have EUCAST breakpoints available, CLSI guidelines were followed (CLSI, 2020). All antimicrobials used are shown in Table 9 and were supplied by Oxoid (Basingstoke, UK).

Table 9: Disk contents used to determine antimicrobial susceptibility of *E. coli* isolates and source of clinical breakpoints

Antimicrobials	Disk content	Source
Neomycin	30µg	N/A
Spectinomycin	100µg	N/A
Tetracycline	30µg	CLSI
Amoxicillin/Clavulanic Acid	20-10µg	EUCAST
Ciprofloxacin	5µg	EUCAST
Ampicillin	10µg	EUCAST
Sulfa-Trim	23.75-1.25µg	EUCAST
Chloramphenicol	30µg	EUCAST
Cefotaxime	5µg	EUCAST
Imipenem	10µg	EUCAST

4.3.6. Terminology

Epidemiological cut-off values determined by EUCAST are referred to by the acronym ECOFF. For differentiation from the ECOFF values, the sheep-specific and beef-specific cut-off values determined by the NRI method in this study are referred to by the acronym sheep CO_{WT} and beef CO_{WT}, respectively.

CO_{WT} and ECOFF values determine wild type (WT) and non-wild type (NWT) organisms, where WT organisms are characterised as devoid of phenotypically-detectable acquired resistance mechanisms. Clinical breakpoints determine susceptible (S) and resistant (R) organisms, where S organisms are characterised by a level of antimicrobial activity associated with a high likelihood of therapeutic success (EUCAST, 2015).

4.3.7. Data analysis

Data cleaning, descriptive analysis, cluster analyses and univariable multilevel logistic regression modelling was carried out in Stata software (Stata SE/16.1, Stata Corp., College Station, TX, USA). The multivariable multilevel logistic regression model was fit in MLwiN 3.02 (Charlton et al., 2017). The isolates obtained from three samples from farm two were excluded from analysis as the sampled sheep were administered antimicrobials within two weeks of the sample date. Two isolates were excluded from analysis as the full resistance profile was not present (a disk had fallen off during incubation).

4.3.7.1. Determining cut-off values

Clinical breakpoints, ECOFFs and CO_{WT} values were used to determine the proportion of fully susceptible/WT organisms. The NRI method was used to calculate sheep CO_{WT} and beef CO_{WT} (Kronvall and Smith, 2016). The CO_{WT} was

determined as 2.5 standard deviations from the mean. The automatic and manual Excel programmes used to calculate the CO_{WT} were made available through courtesy P.Smith, W.Finnegan, and G.Kronvall.

Upon inspection of the disk plots produced using the NRI automatic cut-off calculator, the calculated cut-offs for ciprofloxacin and chloramphenicol for sheep and imipenem and chloramphenicol for beef were deemed inappropriate. This was because of an outlying peak in the high-zone part. For these four NRI calculations, the manual NRI calculator was used instead. Usually, the first drop in the rolling means determines the putative peak used for the NRI calculations, whereas if there was an outlying peak in the high-zone part, the second drop in the rolling means was used to determine the putative peak (Kronvall and Smith, 2016).

The NRI method was used with permission from the patent holder, Bioscand AB, TÄBY, Sweden (European patent No 1383913, US Patent No. 7,465,559).

4.3.7.2. Descriptive statistics

The proportion of susceptible/wild type *E. coli* isolates was calculated for each antimicrobial used for the susceptibility testing. The kappa-statistic was used to measure the level of agreement between the interpretations of clinical breakpoints, ECOFFs and CO_{WT} values. A score of 1 indicated perfect agreement and a score of 0 indicated the amount of agreement that would be expected to be observed by chance (Fleiss et al., 2013). The proportion of farms that had full susceptibility/wild type to each antimicrobial was also calculated.

4.3.7.3. Cluster analysis

To determine potential groupings in AMRs, single linkage hierarchical agglomerative clustering was implemented (Romesburg, 2004). The Jaccard similarity measure was used to compare antimicrobial susceptibility for ten antimicrobials, saving one minus the Jaccard measure as a dissimilarity matrix. Cluster analysis was performed four times to produce dendrograms for antimicrobial susceptibility for (1) sheep isolates using the CO_{WT} values, (2) sheep isolates using clinical breakpoints, (3) beef isolates using CO_{WT} values and (4) beef isolates using clinical breakpoints. A low dissimilarity measure indicated that two antimicrobial susceptibilities were related. A dissimilarity measure of zero indicated that all isolates were susceptible to both antimicrobials.

4.3.7.4. Multilevel logistic regression base model

A binary variable for tetracycline NWT (based on CO_{WT} values) was chosen as the dependent variable as this antimicrobial had the lowest proportion of antimicrobial susceptibility for both sheep and beef isolates. A base model with no predictor variables and three levels was run. If y_{ijk} = 1 if the ith

isolate from sample j from farm k is NWT for tetracycline and y_{ijk} = 0 if it is WT for tetracycline, then we model:

$$y_{ijk} \sim Bernouilli(\pi_{ijk})$$

$$logit(\pi_{ijk}) = \beta + v_k + u_{jk}$$

$$v_k = N(0, \sigma_v^2), u_{jk} \sim N(0, \sigma_u^2)$$

Where β is the probability of the isolate being NWT, u_{jk} is the sample effects (with variance σ_u^2) and v_k is the farm effects (with variance σ_v^2).

4.3.7.5. Multivariable multilevel random-intercept logistic regression

Additional data were collected to investigate risk factors that might be associated with tetracycline non-susceptibility, based on the findings of previous research (Varga et al., 2009, Berge et al., 2010, Bosman et al., 2014, Markland et al., 2019, Schubert et al., 2021). Meteorological data were extracted from UK Meterological Office data (Met Office, 2020). The average maximum and minimum temperature (°C), and rainfall (mm) from the closest weather station for the month of sample collection was recorded for each farm. Soil data were extracted from the UK Soil Observatory based on the postcode of each farm and are presented in Table 10 (UK Soil Observatory, 2020). AMU data were collected using the bin method (See Section 3.3.4) (Saini et al., 2012). From this, a binary variable for the presence of each antimicrobial class was produced.

Table 10: Metal concentrations of soil from 35 sheep and beef farms based on UK soil observatory data

Variable	Median	IQR
Copper concentration (mg/kg)	20.71	17.52-23.40
Zinc concentration (mg/kg)	78.40	68.91-92.64
Lead concentration (mg/kg)	48.08	43.95-55.05
Cobalt concentration (mg/kg)	11.02	8.84-12.77

A univariable three-level logistic regression analysis was carried out to determine associations with isolates being tetracycline NWT. Variables with p ≤0.2 were considered for the multivariable three-level random-intercept logistic regression model. Initially, model exploration was conducted using first-order marginal quasi-likelihood. Then Markov-chain Monte Carlo (MCMC) simulations using Metropolis–Hastings sampling with diffuse priors, a burn in length of 5000 and a run of 50,000 iterations was used to fit the multivariable model. The Raftery-Lewis diagnostic suggested that a Markov chain of at least 435,000 was needed to estimate the 2.5% quantile for the for the intercept coefficient. Therefore, MCMC simulations with a burn-in length

of 10,000 and a run of 500,000 iterations was used to fit the final multivariable multilevel logistic regression model. The use of a Bayesian multilevel model results in more stable estimates and reduces the Type I error by shrinking estimates towards a group level mean (Gelman et al., 2012).. A forward and backwards selection stepwise model building approach was used, where only variables with p≤0.05 were selected to remain in the model. If y_{ijk} = 1 if the ith isolate from sample j from farm k is NWT to tetracycline and y_{ijk} = 0 if it is WT to tetracycline, then we model:

$$y_{ijk} \sim Bernouilli(\pi_{ijk})$$

$$logit(\pi_{ijk}) = \beta_0 + B_1 TetracyclineUse_{ijk} + \beta_2 CuConc_{ijk} + v_k + u_{jk}$$
$$v_k = N(0, \sigma_v^2), u_{jk} \sim N(0, \sigma_u^2)$$

Where β_0 was the intercept; B_1 was the coefficient for the effect of a unit increase of the predictor $TetracyclineUse_{ijk}$ on the outcome; B_2 was the coefficient for the effect of a unit increase of the predictor $CuConc_{ijk}$ on the outcome; and v_k and u_{jk} were the random-effects at the farm and sample level, respectively.

The VPCs were calculated under the latent variable method which assumes the binary outcome arises from an underlying continuous distribution and that the level 1 variance on the logit scale is $\pi^2/3$ (Leyland and Groenewegen, 2020).

$$VPC_k = \sigma_v^2/(\sigma_v^2 + \sigma_u^2 + \pi^2/3)$$
$$VPC_j = (\sigma_v^2 + \sigma_u^2)/(\sigma_v^2 + \sigma_u^2 + \pi^2/3)$$

Where VPC_k is the VPC at the farm level, VPC_j is the VPC at the sample level, σ_v^2 is the variance at the farm level and σ_u^2 is the variance at the sample level.

Selection of the best fitting model was based on the value of Bayesian Deviance Information Criterion (DIC). The model with the lowest DIC value was considered the best fitting model.

4.4. Results

The total number of isolates tested for each farm is presented in Table 11. A total of 1115 presumptive *E. coli* isolates underwent antimicrobial susceptibility testing. Of these, 699 isolates were from 203 sheep faecal samples on 27 different farms, and 416 isolates were from 134 beef cattle faecal samples on 19 different farms.

Table 11: Number of presumptive *E. coli* isolates tested for each farm by animal origin

Farm no	No sheep isolates	No beef isolates
1	0	30
2	10	15
3	13	16
4	15	16
5	0	32
6	25	15
7	0	32
8	0	36
9	33	0
10	30	0
11	26	17
12	15	0
13	30	0
14	10	13
15	28	0
16	39	0
17	15	15
18	15	15
19	0	30
20	30	0
21	39	0
22	29	0
23	40	0
24	30	0
25	29	0
26	25	15
27	0	30
28	0	30
29	28	0
30	27	15
31	39	0
32	15	15
33	0	29
34	31	0
35	33	0

4.4.1. Comparison of methods to interpret resistance

The cut-off values determined by the NRI method (CO_{WT}) for sheep and beef faecal derived isolates were larger for tetracycline compared with the clinical breakpoints (Table 12). The CO_{WT} values for sheep and beef were larger for ciprofloxacin, sulfamethoxazole-trimethoprim, cefotaxime, and imipenem compared with the clinical breakpoints and ECOFF values. However, CO_{WT} values for sheep and beef were smaller for amoxicillin/clavulanic acid and ampicillin compared with the clinical breakpoints and ECOFF values. All CO_{WT} values had a standard deviation <4.00mm as recommended by Smith et al. (2012). CO_{WT} values with standard deviation between 3.36-4.00mm were referred to as tentative CO_{WT} estimates. For beef cattle, four antimicrobials

had tentative CO_{WT} estimates and for sheep, two antimicrobials had tentative CO_{WT} estimates (Table 12).

Table 12: Epidemiological cut-off values calculated using the NRI method compared with clinical breakpoints and ECOFF values

Antimicrobials	Disk content	Clinical breakpoint (S≥mm)	ECOFF WT ≥ mm	Sheep CO_{WT} WT ≥ mm	SD	Beef CO_{WT} WT ≥ mm	SD
Neomycin	30µg	-	-	13	1.46	14	1.87
Spectinomycin	100µg	-	-	19	1.91	18	2.06
Tetracycline	30µg	15	-	25	2.25	26	2.17
Amoxicillin/Clavulanic Acid	20-10µg	19	16	15	3.15	15*	3.66
Ciprofloxacin	5µg	25	25	27*	3.72	32	2.42
Ampicillin	10µg	14	14	12	3.26	11*	3.61
Sulfamethoxazole-Trimethoprim	23.75-1.25µg	14	21	24	2.96	24	2.72
Chloramphenicol	30µg	17	17	18*	3.50	17*	3.65
Cefotaxime	5µg	20	21	26	2.26	26	3.04
Imipenem	10µg	22	24	27	2.82	27*	3.88

*SD>3.34mm and therefore CO_{WT} only a tentative estimate

Based on CO_{WT} values, 87.9% (980/1115) of all presumptive *E. coli* isolates were defined WT organisms for all ten antimicrobials. Of the beef faecal isolates, 85.1% (354/416) were defined WT for all ten antimicrobials. Of the sheep faecal isolates, 89.6% (626/699) were WT for all ten antimicrobials. The presumptive *E. coli* isolates had the lowest susceptibility to tetracycline, with 92.1% of sheep isolates being WT (Table 13) and 87.7% of beef isolates being WT (Table 14).

Table 13: Prevalence of antimicrobial susceptible (S) and wild type (WT) presumptive *E. coli* isolated from sheep using clinical breakpoints, ECOFFs and the NRI method

Antimicrobial	N Isolates sheep	Clinical breakpoint (% S)	ECOFF (% WT)	Sheep CO_{WT} (% WT)	Kappa
Neomycin	699	-	-	99.6%	N/A
Spectinomycin	699	-	-	95.9%	N/A
Tetracycline	699	93.0%	-	92.1%	0.938
Amoxicillin/Clavulanic Acid	699	95.4%	97.4%	98.1%	0.689
Ciprofloxacin	699	100%	100%	100%	N/A
Ampicillin	699	94.7%	94.7%	95.1%	0.971
Sulfamethoxazole-Trimethoprim	699	98.0%	98.0%	97.9%	0.976
Chloramphenicol	699	99.3%	99.3%	99.3%	1.000
Cefotaxime	699	99.7%	99.1%	98.7%	0.585
Imipenem	699	100%	100%	100%	N/A

Table 14: Prevalence of antimicrobial susceptible (S) and wild type (WT) presumptive *E. coli* isolated from beef cattle using clinical breakpoints, ECOFFs and the NRI method

Antimicrobial	N Isolates beef	Clinical breakpoint (% S)	ECOFF (% WT)	Beef CO_{WT} (% WT)	Kappa
Neomycin	416	-	-	100%	N/A
Spectinomycin	416	-	-	99.0%	N/A
Tetracycline	416	88.2%	-	87.7%	0.977
Amoxicillin/Clavulanic Acid	416	98.3%	99.5%	99.8%	0.395
Ciprofloxacin	416	99.8%	99.8%	99.0%	0.423
Ampicillin	416	97.8%	97.8%	97.8%	1.000
Sulfamethoxazole-Trimethoprim	416	99.5%	99.5%	98.1%	0.495
Chloramphenicol	416	97.6%	97.6%	97.6%	1.000
Cefotaxime	416	99.5%	99.3%	99.0%	0.776
Imipenem	416	100%	100%	100%	N/A

4.4.2. Farm level susceptibility

All presumptive *E. coli* isolated from six farms were WT for the ten antimicrobials based on CO_{WT} values (6/35, 17%). Only 26% (9/35) of farms had all isolates WT to tetracycline, whereas, all farms (35/35) had all isolates WT to imipenem (Table 15).

Table 15: Farm level prevalence of antimicrobial susceptibility of all *E. coli* isolated from sheep and beef farms based on the NRI method and clinical breakpoints

Antimicrobial	Farms with all isolates as wild type/susceptible	
	CO_{WT}	Clinical breakpoint
Neomycin	33/35 (94%)	-
Spectinomycin	21/35 (60%)	-
Tetracycline	9/35 (26%)	10/35 (29%)
Amoxicillin/Clavulanic Acid	30/35 (86%)	18/35 (51%)
Ciprofloxacin	32/35 (91%)	34/35 (97%)
Ampicillin	17/35 (49%)	16/35 (46%)
Sulfamethoxazole-Trimethoprim	22/35 (63%)	26/35 (74%)
Chloramphenicol	27/35 (77%)	27/35 (77%)
Cefotaxime	31/35 (86%)	32/35 (91%)
Imipenem	35/35 (100%)	35/35 (100%)

4.4.3. Cluster analysis

The dendrograms from the single-linkage cluster analysis of susceptibility to eight antimicrobials in presumptive *E. coli* isolated from beef cattle faecal samples and sheep faecal samples are presented in Figure 9.

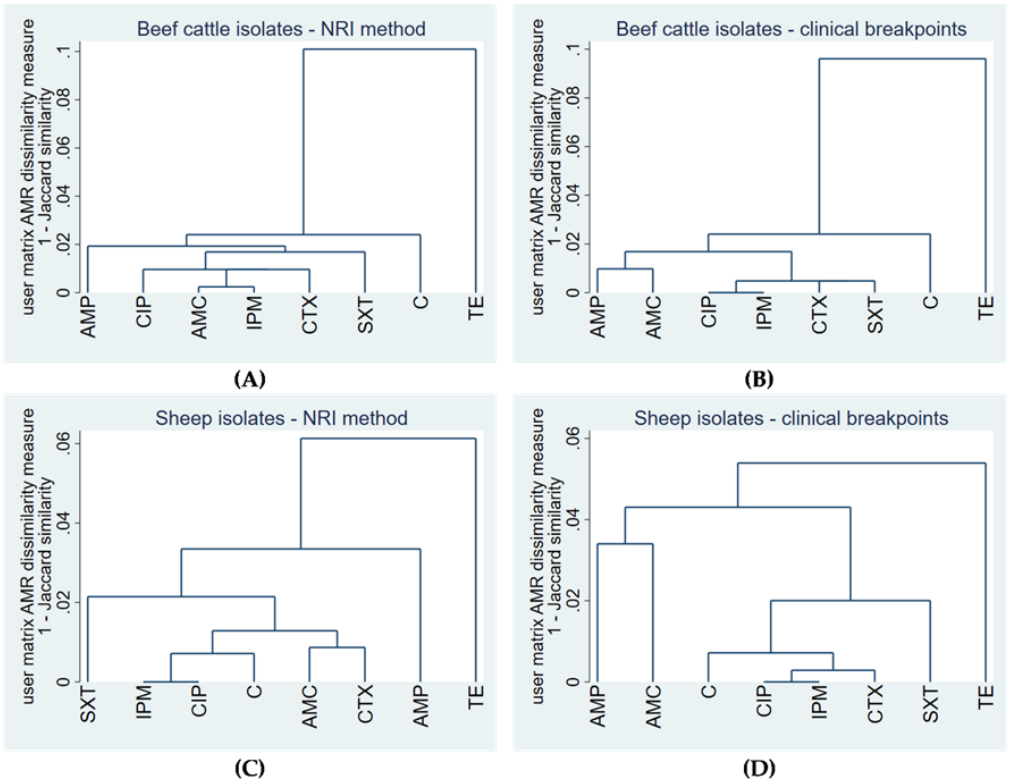


Figure 9: Single-linkage clustering dendrograms for non-susceptibility to eight antimicrobials (A) based on the NRI CO_{WT} values in presumptive *E. coli* isolates from beef cattle faecal samples (n = 416); (B) based on clinical breakpoints, in presumptive *E. coli* isolates from beef cattle faecal samples (n = 416); (C) based on the NRI CO_{WT} values, in presumptive *E. coli* isolates from sheep faecal samples (n = 699); and (D) based on clinical breakpoints, in presumptive *E. coli* isolates from sheep faecal samples (n = 699). AMP=ampicillin, AMC= amoxicillin/clavulanic acid, C=chloramphenicol, CIP=ciprofloxacin, CTX=cefotaxime, IPM=imipenem, SXT= sulfamethoxazole-trimethoprim, TE=tetracycline.

For both the sheep and beef isolates, the cluster analyses using clinical breakpoints identified a cluster of isolates that were non-susceptible to ampicillin and amoxicillin/clavulanic acid. This cluster was not identified when using the NRI CO_{WT} values. In all four cluster analyses, tetracycline was the least related to other antimicrobial susceptibilities. A cluster of sheep isolates NWT for cefotaxime and amoxicillin/clavulanic acid was identified using NRI CO_{WT} values, but not using clinical breakpoints.

4.4.4. Multilevel logistic regression model

4.4.4.1. Base model

The base multilevel logistic regression model indicated that 16% of the variance of an isolate being defined as NWT for tetracycline was due to between-farm differences and 76% of the variance was due to between-sample differences.

4.4.4.2. Univariable multilevel logistic regression models

A univariable multilevel logistic regression analysis was carried out to determine potential factors associated with the presence of tetracycline NWT isolates. Table 16 presents the associations of potential risk factors.

Table 16: Univariable multilevel logistic regression analysis for risk factors associated with presumptive *E. coli* defined as non-wild type for tetracycline

Factor	Unit	N	Odds ratio (95% CI)	p-value
Flock size	No ewes	1115	0.91 (0.46, 1.81)	0.792
Herd size	No cattle>12months	1115	0.90 (0.44, 1.82)	0.761
Region: Wales	No	737		
	Yes	378	1.62 (0.37, 7.11)	0.523
Region: West Midlands (England)	No	790		
	Yes	325	1.08 (0.23, 5.13)	0.924
Region: Southern England	No	823		
	Yes	242	0.39 (0.07, 2.25)	0.292
Indoor samples	No	568		
	Yes	547	2.90 (0.77, 10.97)	0.116
Mixed species farm	No	362		
	Yes	753	1.93 (0.41, 9.09)	0.404
Animal species sample origin	Cattle	416		
	Sheep	699	0.38 (0.11, 1.28)	0.118
Maximum average temperature of sampling month	°C	1115	0.90 (0.45, 1.79)	0.760
Minimum average temperature of sampling month	°C	1115	0.79 (0.49, 1.95)	0.939
Average rainfall in sampling month	Mm	1115	1.23 (0.62, 2.42)	0.556
Tetracycline use	No	159		
	Yes	956	22.21 (1.46, 337.52)	0.026
Penicillin use	No	157		
	Yes	958	0.62 (0.09, 4.44)	0.635
Aminoglycoside use	No	363		
	Yes	752	0.52 (0.12, 2.19)	0.376
Macrolide use	No	634		
	Yes	481	1.95 (0.48, 7.90)	0.384
Phenicol use	No	825		
	Yes	290	6.98 (1.82, 26.80)	0.005
Sulphonamide use	No	993		
	Yes	122	2.60 (0.32, 21.03)	0.371
Soil copper concentration	Mg/kg	1115	1.72 (0.97-3.05)	0.062
Soil zinc concentration	Mg/kg	1115	0.90 (0.45, 1.78)	0.755
Soil lead concentration	Mg/kg	1115	1.60 (0.85, 3.00)	0.144
Soil cobalt concentration	Mg/kg	1115	0.65 (0.34, 1.26)	0.206

4.4.4.3. Multivariable multilevel logistic regression model

The odds of isolates being defined as NWT for tetracycline was 28 times higher (CI=2.50-520.09) when farms used tetracycline antimicrobials in their

animals (Table 17). With every standardised unit increase for soil copper concentration, the odds of isolates being defined as NWT for tetracycline were 1.78 times higher (CI=1.02-3.21). A variable for phenicol use was not included in the final model because it was no longer significant when other variables were included in the model.

Table 17: Multivariable multilevel logistic regression analysis for risk factors associated with presumptive *E. coli* isolates being defined as non-wild type for tetracycline

Variable	Unit	N	Odds ratio (95% CrI)	p-value
Tetracycline use	No	159		
	Yes	956	28.22 (2.50, 520.09)	0.014
Soil copper concentration	Mg/kg	1115	1.78 (1.02, 3.21)	0.046
Random effects			**Variance estimate (95% CrI)**	
Farm			1.24 (0.003, 4.47)	
Sample			9.36 (4.86, 16.38)	

The multivariable multilevel logistic regression model indicated that 9% of the residual variance of an isolate being defined as NWT for tetracycline was due to between-farm differences and 76% of the residual variance was due to between-sample differences.

4.5. Discussion

In this study, AMR patterns in *E. coli* isolated from sheep and beef farms was assessed using different interpretation methods. The results show that AMR in faeces on sheep and beef farms in England and Wales is generally low regardless of interpretation method, compared with samples from other livestock species in the UK (VMD, 2020b). However, interpretation method can have important implications on the understanding of resistance patterns. Different clusters of resistance patterns were determined when using clinical breakpoints compared with bespoke cut-off values using the NRI method.

The comparison of susceptibility interpretation methods showed that differences in the proportion of susceptible isolates may occur depending on the method used. There was little correlation between interpretations of susceptibility using clinical breakpoints, ECOFFs and CO_{WT} values for amoxicillin/clavulanic acid in particular. For the beef isolates, there was also little correlation between the interpretations for ciprofloxacin and sulfamethoxazole-trimethoprim. The results suggest that clinical breakpoints and ECOFFs are not appropriate for interpreting AMR in bacteria isolated from sheep or cattle faeces as they do not fit the WT distribution of isolates. Silva et al. (2020) showed that clinical breakpoints and ECOFFs may be inappropriate for the classification of ovine isolates as resistant and that these interpretation methods may over-report AMR in sheep populations. The results of this study also indicate that clinical breakpoints and/or ECOFFs may

slightly under-report, as well as over-report, AMR in sheep and beef isolates, particularly for sulfamethoxazole-trimethoprim, tetracycline and cefotaxime.

Silva et al. (2020) further suggest that the sheep industry could establish sheep-specific cut-offs to avoid over-interpretation of resistance in ovine isolates. It is important to highlight that some of the sheep-specific cut-offs determined in the study by Silva et al. (2020) were vastly different to those determined in this study. For example, Silva et al. (2020) calculated the sheep CO_{WT} for tetracycline to be 14mm, whereas a sheep CO_{WT} of 25mm was calculated in this study. The difference could be because of differences in the study population. The present study investigated sheep samples from 27 farms in England and Wales, whereas Silva et al. (2020) used samples from three farms in Scotland and one farm in Norway. Additionally, some isolates collected by Silva et al. (2020) were from diseased animals and not from faecal samples. Nevertheless, this demonstrates the need for large scale data collection from a variety of different farms before industry-wide cut-off values can be developed. These results also demonstrate the need to use the NRI method to calibrate the disk diffusion test to compare results between laboratories.

The differences in interpretation methods led to disparities in the groupings of AMRs through cluster analysis. There was a cluster of isolates that were non-susceptible to ampicillin and amoxicillin/clavulanic acid for both the sheep and beef samples when the clinical breakpoints were used, but were not clustered as NWT when CO_{WT} values were used. A cluster of sheep isolates that were NWT for cefotaxime and amoxicillin/clavulanic acid was only determined with the CO_{WT} values. This may have implications for elucidating resistance mechanisms. Non-susceptibility to amoxicillin/clavulanic acid and ampicillin or cefotaxime suggests mechanisms of beta-lactam resistance which requires further investigation through genotypic analysis (Li et al., 2007). These non-susceptibility and NWT patterns may have been missed if only one interpretation method was used.

A few cases of cefotaxime non-susceptibility in sheep and beef faecal isolates were reported in this study. Reduced susceptibility to cefotaxime has been reported in British beef cattle (Velasova et al., 2019). Although cefotaxime resistance in isolates from sheep have previously been reported in England and Wales, these were from clinical diagnostic samples (Snow et al., 2011) and, to the authors knowledge, it has not been reported for apparently healthy sheep in England and Wales before. This may be because third-generation cephalosporins are very rarely used on sheep farms. The use of highest-priority CIAs should only be used as a last resort, when susceptibility testing has been conducted and no other antimicrobial would be effective. As resistance to other lower priority antimicrobials is uncommon in sheep and beef cattle, the use of third-generation cephalosporins is usually not required.

It has previously been shown that cefotaxime resistant bacteria may be present on beef farms without any AMU and that the environment may be a source of cefotaxime resistance (Mir et al., 2018, Markland et al., 2019). The presence of cefotaxime non-susceptibility raises concerns around the existence of ESBLs in healthy sheep and beef cattle (Li et al., 2007), especially as a group of sheep isolates resistant to both cefotaxime and amoxicillin/clavulanic acid were identified from the cluster analysis. Further screening of the cefotaxime non-susceptible isolates is required to determine the presence of ESBL resistance mechanisms (EUCAST, 2017).

The results suggest that AMR to commonly used antimicrobials (such as tetracycline and penicillin) in apparently healthy sheep and beef cattle in England and Wales is much lower than that reported from national clinical surveillance (Cheney et al., 2015, VMD, 2020b). This is probably because clinical samples are more likely to come from sick animals that have already been treated with antimicrobials before submission. Additionally, beef and dairy cattle samples are not separated when reporting AMR (VMD, 2020b). In apparently healthy dairy cattle, the proportion of resistant isolates is much higher than the beef cattle reported here (Schubert et al., 2021). Although AMR appears to be low on sheep and beef farms in England and Wales, these figures were higher than what was reported historically. In 1999, 3% of isolates from sheep, and 6% of isolates from cattle were resistant to one or more antimicrobials (Enne et al., 2008). In contrast, in our study 10% of isolates from sheep, and 15% of isolates from cattle were NWT for one or more antimicrobials. Similarly, less than 4% of *E. coli* isolates from Scottish beef farms between 2001 and 2004 were resistant to tetracycline (Vali et al., 2007), compared with 12% of beef isolates in our study. This difference in susceptibility may be due to differences in study design; for example, differences in the antimicrobials studied or sampling technique. Additionally, the use of different interpretation methods may play a role in the varying antimicrobial susceptibilities as an organism that is classed as NWT does not necessarily display clinical resistance. Alternatively, differences in susceptibilities between the studies may be due to changes in farm practices over the last twenty years. This highlights the need for regular and consistent surveillance of AMR on sheep and beef farms in the UK so that longitudinal comparisons can be made.

The majority of the variance in antimicrobial susceptibility between isolates was due to between-sample differences, whereas only a small proportion of variance was due to between-farm differences. Around half of the between-farm variance could be explained by the use of tetracycline on farm and the concentration of copper in the soils; however, there was still a large proportion of between-sample variation that was unexplained. This suggests that differences in AMR patterns are due to the variability in management of individual animals rather than any whole flock or herd management practices.

The results probably reflect that antimicrobials are not usually used as routine prophylactic treatments on sheep and beef farms in the UK, and in most cases farmers only use antimicrobials for the treatment of sick individual animals (Doidge et al., 2020c, Doidge et al., 2020b). This is encouraging as there has been a large push in the UK agriculture industry to voluntarily reduce AMU over the last five years, especially for whole flock and herd treatments (Doidge et al., 2020c, RUMA, 2020). The large sample level variance may also be due to the individual characteristics of the animals. For example, cattle over the age of 25 months have been shown to carry significantly less antimicrobial resistant *E. coli* compared with younger cattle (Mainda et al., 2015). It was not possible to gather much sample-level information in this study as faecal samples were collected from the ground rather than directly from the animals. To understand the sources of variance at the sample-level, further investigation using samples obtained directly from individual animals is recommended. The high variability between samples suggests that future studies that aim to understand the drivers of AMR on farms should consider taking individual animal samples rather than pooled samples.

The use of phenicols and tetracyclines was significantly associated with tetracycline NWT isolates in the univariable analysis. The association between tetracycline use and tetracycline NWT isolates is not surprising and has previously been reported for other livestock species (Varga et al., 2009, Gibbons et al., 2016). The use of a particular antimicrobial will result in the direct selection of the corresponding resistance (Harada and Asai, 2010). Phenicol use might indirectly select for tetracycline resistance via cross-resistance mechanisms. Alternatively, phenicol use may be associated with tetracycline NWT isolates if farmers change their antimicrobial drug of choice from tetracycline to phenicol when they find tetracyclines are no longer as effective for them. Tetracyclines are used as first line treatments for livestock in the UK, whereas, phenicols are in a higher category of antimicrobial which should only be used when first line treatments are unavailable; for example, in cases of clinical tetracycline resistance (EMA, 2019). Other factors that were identified as significant influences on AMR in previous studies, such as weather (Schubert et al., 2021) and farm size (Mainda et al., 2015), were not significantly associated with tetracycline NWT isolates in this study. One possible reason for this is that there were only a small proportion of tetracycline NWT isolates in this study.

The concentration of copper in the soils in the farm area and the use of tetracyclines were significantly associated with tetracycline NWT isolates in the multivariable analysis. Previous research indicates that the geochemical conditions of soils, particularly copper concentrations, are correlated with the abundance of AMR genes (Knapp et al., 2011, Knapp et al., 2017). Furthermore, copper has been shown to co-select for tetracycline resistance in experimental conditions (Song et al., 2017), and mathematical models

suggest that this co-selection may occur at copper concentrations as low as 5.5 mg/mL (Arya et al., 2021). The results of this study suggest that tetracycline non-susceptibility may be more prevalent on some farms due to the environmental exposure to copper in soils. Sheep and cattle might be exposed to copper in soils when grazing in fields and ingestion of copper could co-select for tetracycline resistance, leading to a higher prevalence of tetracycline-resistant faecal *E. coli* (Amachawadi el al., 2013). There needs to be further investigation into the presence of copper resistance genes in the tetracycline NWT isolates obtained in this study.

4.5.1. Limitations

The study sample was small. However, the number of farms was comparable to that of similar studies investigating AMR at the farm level and the farms represented a range of farm types and sizes (Carson et al., 2008a, Schmid et al., 2013). Additionally, the farms were mainly located in Wales and the West of England, where sheep and cattle are more densely populated (APHA, 2018a, APHA, 2018b). This was a cross-sectional study and so changes in AMR over time could not be measured. Additionally, information was mainly only collected at the farm level, but analysis indicated that most of the variation in resistance was at the sample level. Further investigation using a longitudinal study design and collecting sample level information from individual animals is required to understand additional variation in resistance levels on farms. The isolates in this study were selected from TBX plates and no further tests were carried out to confirm the identity of the strains. Therefore, the isolates may only be considered as presumptive *E. coli* isolates. This may be why some of the calculated CO_{WT} values had a standard deviation over 3.34mm and had to be considered tentative estimates.

4.6. Conclusions

Antimicrobial non-susceptibility of *E. coli* isolated from healthy sheep and beef cattle in England and Wales appears to be low compared with reports from clinical diagnostic isolates. However, antimicrobial non-susceptibility from healthy animals may have increased in the past twenty years. The use of tetracyclines on farms and environmental copper exposure in soils may contribute to tetracycline resistance. Uniform methods of antimicrobial susceptibility testing are required to make longitudinal comparisons and monitor long-term changes in resistance patterns. Using human clinical breakpoints could lead to the under-reporting and over-reporting of antimicrobial resistance in sheep and beef cattle. The use of livestock-specific cut-off values for interpreting antimicrobial susceptibility can provide more appropriate estimates of susceptibility for sheep and beef cattle.

5. Study 3: To prescribe or not to prescribe? A factorial survey to explore veterinarians' decision-making when prescribing antimicrobials to sheep and beef farmers in the UK

This chapter has been published in a peer-reviewed journal:

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Author contributions:

All authors helped to conceptualise the study and worked on the methodology. For example, discussions were held about the wording of the survey questions and vignettes. CH, FL and JK supervised the project. CD had roles in data curation, formal analysis, investigation, project administration, validation, visualization, and writing (original draft). JK assisted with the formal analysis. For example, discussions with CD around which data analysis methods to use. All authors reviewed and edited the final manuscript.

5.1. Abstract

Whilst there are many studies in human medicine investigating prescribing behaviour of doctors, there is limited work to understand what factors influence veterinarian prescribing behaviour. Veterinarians often prescribe antimicrobials to sheep and beef farmers in contexts other than at a clinical consultation, and decision-making behind this has not been explored. The aim of this study was to measure the influence of factors from social theories on veterinarians' decisions to prescribe antimicrobials to sheep and beef farmers without a clinical consultation using a factorial survey approach. Respondents were presented with eight vignette scenarios, where a farmer asks for antimicrobials at the veterinary practice. Seven factors identified from constructs of social theories were included in the vignettes. Random intercept and random slope models were built to estimate the effects of the vignette factors and veterinarian characteristics on the respondents' willingness to prescribe ratings. A total of 306 surveys were completed. The vignette factors: case type, farmer relationship, other veterinarians in practice, time pressure, habit, willingness to pay, and confidence in the farmer, were significant in the decision to prescribe. Confidence in the farmer was the most influential vignette variable, and was included as a random slope effect.

Respondent variables with significant influence on the decision to prescribe were agreeableness personality score, region of veterinary practice, and presence of a small animal department. These influential factors could be considered in intervention studies aimed at improved antimicrobial stewardship in beef and sheep veterinary practice.

5.2. Introduction

One of the priorities towards tackling the threat of AMR is to ensure responsible use of antimicrobials in agriculture, which can be achieved through understanding the decision-making process around prescribing antimicrobials (O'Neill, 2016). Studies have shown that veterinarians were the most influential source of information for farmers' AMU (Etienne et al., 2017). In the UK, veterinary antimicrobials are a prescription only medicine (POM-V) which can only be prescribed by a veterinarian. Veterinarians generally have very little presence on sheep and beef farms in particular, and are often only called onto the farm in emergencies (Lowe, 2009, Kaler and Green, 2013). According to the Code of Professional Conduct for Veterinary Surgeons, veterinarians can prescribe as long as the animal has been seen "recently enough or often enough for the veterinary surgeon to have personal knowledge of the condition of the animal or current health status of the herd or flock to make a diagnosis". Therefore, it is not uncommon for farmers to receive antimicrobials from veterinarians without a clinical consultation in which animals are examined at the time of prescription.

A previous study using veterinary prescription records estimated that there is huge variability in usage among sheep farms (Davies et al., 2017), which may indicate that some farms could be using antimicrobials unnecessarily, and veterinarians prescribing inappropriately. The study also showed that 21% of variation in the usage could be attributed to the veterinary practice. Coupled with antimicrobials having POM-V status, this suggests that veterinarian prescription behaviour plays an important role in AMU at the farm level.

In order to investigate what is causing these differences in veterinary prescription, studies into the human behaviour regarding AMU are necessary. There has been limited research in the area of veterinarian decision-making. Most of the work on this topic used qualitative methods to explore factors that influence prescribing behaviour (Coyne et al., 2014, Mateus et al., 2014, Speksnijder et al., 2015a, Coyne et al., 2016). The studies identified psychosocial factors such as relationship with clients, previous experience, and risk avoidance. While these studies give some insights into what factors influence veterinary behaviour towards prescribing antimicrobials, it is unknown how these factors are represented in a larger population of veterinarians, and the relative importance of these factors in influencing veterinarians' decisions. The limited number of quantitative studies that

explore veterinarian antimicrobial prescribing behaviours over a larger population often focus on enterprises other than sheep and beef, such as pigs (Visschers et al., 2016a, Coyne et al., 2018). The few studies that do include prescribing to beef farmers may over-simplify the prescribing decision through asking about each potential factor individually (Busani et al., 2004, De Briyne et al., 2013, Gibbons et al., 2013). Therefore, the ecological validity is compromised, as the decision does not mimic "real-life" conditions. As of yet, veterinary antimicrobial prescribing behaviour towards sheep farmers in the UK has not been investigated. In addition, since the work exploring veterinarian prescribing behaviour has not used any underpinning theoretical framework, the role of additional factors is unknown. Finally, due to the lack of veterinarian involvement on sheep and potentially beef farms, prescribing in contexts other than clinical consultation is common (Lowe, 2009). Veterinarians prescribing behaviour in this setting has not been explored before.

Physician prescribing behaviour has been much more comprehensively researched when compared to veterinarian prescribing behaviour, and has identified the influence of factors such as other staff members, pressure from patients, and past behaviour (Walker et al., 2001, Eccles et al., 2007). This work relied on a range of social-cognitive theories to study healthcare professional's behaviours, with the Theory of Planned Behaviour (TPB) most commonly used (Godin et al., 2008). There is evidence from the health psychology domain to suggest that cross-theory constructs could explain more variation in behaviour than using constructs from a single theory (Hagger and Chatzisarantis, 2014). This has not been applied or tested for veterinarian decision-making. One challenge in understanding decision-making is that decisions are complex and are not made in a social vacuum which can results in social desirability bias. This is of particular importance for measuring antimicrobial prescription behaviour, due to the public and media attention AMU in agriculture receives. To address this, factorial survey methods have been used widely in social care (Killick and Taylor, 2012), criminology (Lyons, 2008), and clinical decision-making, however, are yet to be used in veterinary decision-making (Chatfield et al., 2017). The aim of this study was to use, for the first time in veterinary decision-making, a factorial survey approach to measure the influence of factors from various social theories on veterinarians' decisions to prescribe antimicrobials to sheep and beef farmers, without a clinical consultation first. It was hypothesised that certain social-psychological factors were associated with veterinarians' likelihood to prescribe antimicrobials.

5.3. Methods

5.3.1. Factorial survey approach

5.3.1.1. Study design

Respondents were presented with a series of eight vignettes which mimic a real life scenario. Each vignette was comprised of seven factors, where the factors had between two and four possible levels. A total of 384 unique vignette combinations were possible. The vignette combinations were randomly selected using a resolution V D-efficient design from a sample of the original 384 (Kuhfeld, 2010).

5.3.2. Scenario and dependent variables

The scenario used in the vignettes was presented as a farmer coming into the veterinary practice and requesting some antimicrobials from the veterinarian. Scenarios were reviewed by authors who are trained veterinarians to check for plausibility. The respondents were informed that in all scenarios the farmer is requesting an antimicrobial that is licensed for use in sheep and cattle, and is not a high-priority CIA. To reduce ambiguity, the EMA definition of CIAs was included, in which fluoroquinolones, third- and fourth-generation cephalosporins, and colistin were recognised as high priority CIAs.

The respondents were asked to rate two questions relating to this scenario at the end of each vignette (Figure 10):

(1) (Outcome A) how likely the veterinarian in the scenario would prescribe antimicrobials to the farmer, from -5 (definitely would not prescribe) to +5 (definitely would prescribe);

(2) (Outcome B) the percentage of veterinarians that they think would prescribe in that situation, from 0% to 100%.

The rating scale -5 to +5 was used as with previous factorial survey research (Auspurg and Hinz, 2014). Outcome B was asked to allow for the identification of the perceived prescribing norm.

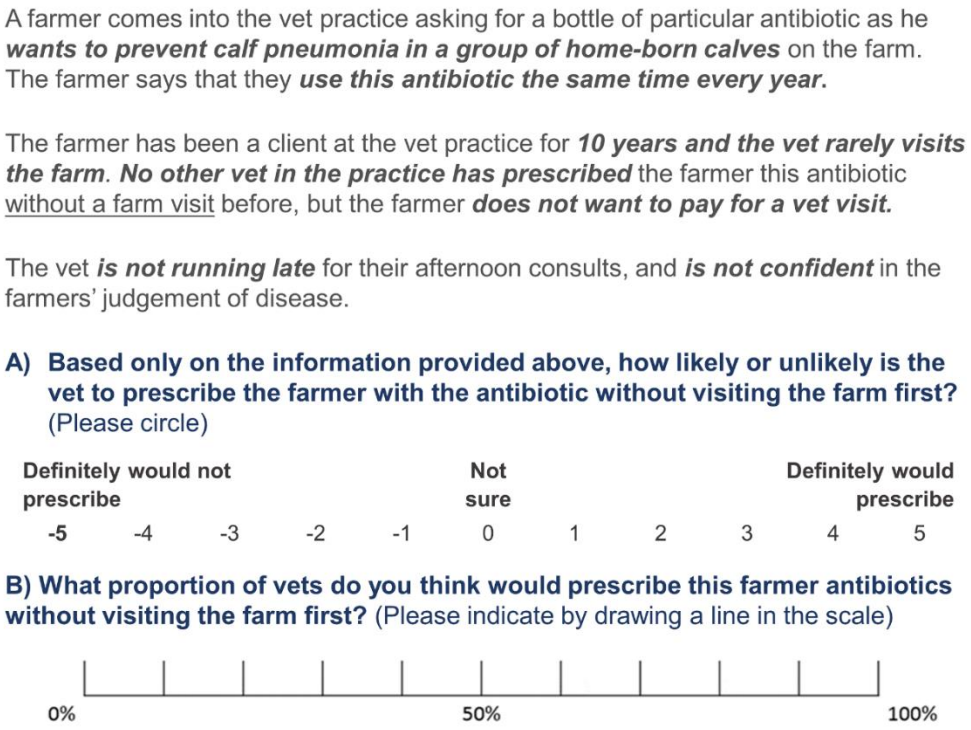


Figure 10: Example vignette used in the factorial survey

5.3.3. Vignette predictor variables

Variables included in the vignettes represented key constructs from multiple social theories, presented below in Table 18. These variables were identified from previous research in veterinarian and physician decision-making (Godin et al., 2008, Gibbons et al., 2013, Coyne et al., 2016). Watery mouth in lambs and calf pneumonia were chosen as diseases for the "knowledge of case" variables as they are common neonatal diseases where antimicrobials may be given either for treatment or prevention (Pardon et al., 2012, RUMA, 2017).

Table 18: Variables included in the factorial survey vignettes, and the theoretical constructs they represent

Variable	Level	Theory construct
Knowledge of case	1. Farmer suspects case of calf pneumonia. 2. Farmer suspects case of watery mouth. 3. Farmer wants to prevent watery mouth. 4. Farmer wants to prevent calf pneumonia.	Epistemological – dependent on their existing knowledge on antimicrobials
Farmer relationship influence	1. The farmer is a long term client and the veterinarian regularly visits his dairy herd but not as involved with the sheep or beef cattle. 2. The farmer is a long term client and the veterinarian rarely visits the farm. 3. The farmer is a new client.	Commitment in commitment-trust theory (Morgan and Hunt, 1994)
Veterinarian influence	1. Other veterinarians in the practice have given the farmer this antimicrobial before without consultation. 2. No other veterinarian in the practice has given the farmer this antimicrobial before without consultation.	Social influence construct found in: TPB (Ajzen, 1991), Theory of Interpersonal Behaviour (Triandis, 1977)
Time pressure	1. No time pressure for prescription. 2. Running late for afternoon surgery consults.	Can alter decision-making process according to cognitive continuum theory (Standing, 2008)
Habit	1. The farmer comes in for the same medication the same time every year. 2. The farmer has never used the antimicrobial for this reason before.	Component of Theory of Interpersonal Behaviour
Willingness to pay	1. Farmer does not want to pay for a veterinary visit. 2. Farmer says they are happy for a veterinary visit.	Perceived behavioural control in TPB, and facilitating conditions in Theory of Interpersonal Behaviour

Confidence	1. The veterinarian is confident in the farmers' judgement of the disease. 2. The veterinarian is not confident in the farmers' judgement of disease.	Trust in commitment-trust theory

5.3.4. Other predictor variables

As well as the vignette variables, closed questions on respondent characteristics were included in the survey: age, gender, university of graduation, year of graduation, position in practice, and time spent with sheep and cattle. Respondents were also asked questions about their practice: region, practice type, and number of veterinarians employed.

The ten item personality inventory was used to obtain personality scores for each veterinarian for extraversion, agreeableness, conscientiousness, emotional stability, and openness to experiences (Gosling et al., 2003). The ten item personality inventory is a very brief measure of personality. It comprises of ten statements relating to the five aforementioned personality variables. Two statements were provided for each variable to reflect both the high and low poles of the personality trait. The statements were rated on a 7 point scale from strongly disagree to strongly agree.

Scores of corresponding statements were averaged to produce an overall score for "The Big Five" personality traits using methods stated by Gosling, Rentfrow and Swann (Gosling et al., 2003).

5.3.5. Study sample and survey distribution

The anonymous survey took approximately fifteen minutes to complete and was piloted on eight farm veterinarians, all of which worked in practice, three of which also worked in academia. Some changes were made to the wording of questions. For example, the definition of CIAs was included after the pilot study as it became apparent that there were different interpretations available. After changes were made, all 813 UK veterinary practices who treat sheep and cattle according to the RCVS website were mailed the English-language paper-based survey in March 2018.

Initially, each veterinary practice received three copies of the survey as it was unknown how many veterinarians in practice worked with sheep or beef cattle. A copy of the initial recruitment letter and survey can be found in Appendix 4 and Appendix 5, respectively. The mail package also included three self-addressed prepaid envelopes to enhance response rate. A reminder letter was sent to non-responding veterinarian practices six weeks after the original survey was sent. A final reminder letter with another copy of the

survey and a pre-paid enveloped was sent to non-responding practices four weeks later.

The estimated sample size was calculated using G*Power for a multiple regression analysis with up to 32 predictor variables (Faul et al., 2009). For a small effect size of 0.02 and power of 0.95 a sample of 1842 was required. As the unit of analysis was the vignette, and each respondent rates eight vignettes, a sample of 230 respondents was required for analysis.

5.3.6. Ethics

Every survey pack contained a recruitment letter and information sheet which gave information on the purpose of the study and the participants' data protection rights (Appendix 4). By returning a completed survey, respondents gave consent that the information supplied could be used in this study.

The study was approved by School of Veterinary Medicine and Science Ethics Committee (no 1850 160916) (Appendix 2).

5.3.7. Data analysis

5.3.7.1. Data handling and univariable analysis

All data were processed and checked for errors using Stata 15.1 software (Stata SE/15.1, Stata Corp., College Station, TX, USA). Descriptive statistics and univariable analysis were carried out to explore the data. Regions of veterinary practice, personality score and age were used as categorical variables. For the likelihood to prescribe (outcome A), the original outcome rating scale of -5 to +5 was recoded to a 1-11 scale. For percentage of veterinarians that they thought would prescribe (outcome B), the respondents rating of 0-100% were grouped to the nearest 10% and coded from 1-10. Both outcomes were treated as continuous variables as recommended by Auspurg and Hinz (2014).

5.3.7.2. Multilevel modelling

For each outcome, multilevel linear models were built using MLwiN 3.02 (Charlton et al., 2017). Initially, model exploration was conducted using first-order marginal quasi-likelihood. In all models a stepwise model building approach was used, where all vignette variables were included in the models and only veterinarian variables with p≤0.05 were selected to remain in the models. Then MCMC simulations using Gibbs sampling with diffuse priors, a burn in length of 500 and a run of 200,000 iterations was used to fit the multivariable model. The Raftery-Lewis diagnostic was used to assess the required Markov chain length and chain mixing was assessed visually. First random intercept models (Model 1A and Model 1B) were built and took the form:

$$y_{ij} = \beta_{0ij} + \beta_{x1} vignettevariables_{ij} + \beta_{z1} vetvariables_{j} + u_{0j} + e_{0ij}$$

Then, a random slope term was included for the confidence vignette variable (Model 2A and Model 2B), to allow for between-respondent variation for the influence of confidence on vignette ratings. Therefore, the random slope models took the form:

$$y_{ij} = \beta_{0ij} + \beta_{x1} vignettevariables_{ij} + \beta_{z1} vetvariables_j + u_{0j} + u_{1j} confidence_{ij} + e_{0ij}$$

Where y_{ij} was the outcome of likelihood to prescribe rating (Outcome A) or percentage of veterinarians who would prescribe (Outcome B) for the *i*th vignette situation, rated by the *j*th veterinarian; β_{0ij} was the intercept; β_{x1} was the coefficient for the effect of a unit increase of the predictor x_{ij} on the outcome; β_{z1} was the coefficient for the effect of a unit increase of the predictor z_j on the outcome; u_{0j} and e_{0ij} are the random effects at the veterinarian and vignette levels respectively; and u_{1j} was the random term for the coefficient of the confidence variable.

K-fold cross validation was carried out in Stata 15.1 software to check model performance and validity and ensure consistency of results between folds. The Mean Absolute Error (MAE) was calculated. To compare model performance of the random intercept and random slope models, the Bayesian Deviance Information Criterion (DIC) was calculated. The model with the lowest DIC value was considered the best fitting model. . Additionally, the Variance Partitioning Coefficient (VPC) was calculated for each model to determine the proportion of variance attributable to the respondent level. The R^2 values were calculated based on methods of Nakagawa and Schielzeth (2013) and Johnson (2014) using the MuMIn R package in RStudio (Barton, 2018, R Core Team, 2018).

5.4. Results

5.4.1. Respondent demographics

A total of 306 surveys were completed and were received from 199 different veterinary practices. This gave a practice response rate of 24%. There were a total of 2448 vignette evaluations. The respondent characteristics are described in Table 19. Of the respondents, 47.8% were female. Almost half (48.5%) of the respondents were aged 30 or under, with over half (52.8%) graduating after 2010.

Table 19: Descriptive statistics of respondent characteristics

Characteristic	Percentage %	Number	
Gender of respondent			
Male	51.8	158	
Female	47.8	146	
Other	0.3	1	
Age of respondent			
30 or under	48.5	148	
31-40	24.6	75	
41 and over	26.9	82	
Year of graduation			
After 2010	52.8	161	
2001-2010	21.3	65	
Before 2001	25.9	79	
University of graduation			
Bristol	12.5	38	
Cambridge	5.6	17	
Dublin	4.3	13	
Edinburgh	16.7	51	
Glasgow	15.4	47	
Liverpool	12.8	39	
Nottingham	7.5	23	
RVC	13.1	40	
Other	12.1	37	
Region of veterinary practice			
Central England	10.5	32	
North East England	8.6	26	
North West England	16.1	49	
South East England	10.9	33	
South West England	21.7	66	
Northern Scotland & the Highlands	10.9	33	
Southern & Central Scotland	7.2	22	
Wales	7.9	24	
Northern Ireland	6.3	19	
Position in practice			
Assistant	61.6	188	
Associate/clinical lead	11.8	36	
Locum	1.3	4	
Practice partner	25.3	77	
Practice type/Work type			
Farm	17.7/34.1	54/104	
Farm & equine	6.6/11.8	20/36	
Farm & small animal	14.8/13.1	45/40	
Farm, equine & small animal	61.0/41.0	186/125	
Number of veterinarians in practice	**Median**	**25% IQR**	**75% IQR**
Full time	6	4	10
Part time	1	0	3
% time spent	**Median**	**25% IQR**	**75% IQR**
With dairy cattle	30	5	60
With beef cattle	20	10	33
With sheep	10	5	20
In an advisory role for dairy	20	3	40
In an advisory role for beef & sheep	20	10	40

5.4.2. Multilevel models

Model 1A, a random intercept model for the respondents' likelihood to prescribe ratings (Outcome A), and Model 2A, including a random slope effect for the variable of veterinarians' confidence in farmer's judgement, are presented in Table 20.

Table 20: Random slope and random intercept models to explain the veterinarians' likelihood to prescribe antimicrobials to a sheep and beef farmer vignette ratings (Outcome A)

	Model 1A		Model 2A	
Outcome A	**β**	**SE**	**β**	**SE**
Case type				
Farmer suspects calf pneumonia	ref		ref	
Farmer suspects watery mouth	0.441**	0.127	0.402**	0.126
Farmer wants to prevent calf pneumonia	-0.958***	0.127	-0.993***	0.125
Farmer wants to prevent watery mouth	0.223	0.129	0.129	0.126
Farmer relationship				
The farmer is a client of 10 years and the veterinarian rarely visits the farm	ref		ref	
The farmer is a client of 10 years and the veterinarian regularly visits his dairy herd	0.612***	0.112	0.614***	0.111
The farmer has been a client for less than a year	-0.339**	0.110	-0.331**	0.108
Other veterinarians in practice				
No other veterinarian in the practice has prescribed the farmer this antimicrobial before without consultation	ref		ref	
Other veterinarians in the practice have prescribed the farmer this antimicrobial before without consultation	0.686***	0.090	0.688***	0.091
Time pressure				
The veterinarian is running late for afternoon consults	ref		ref	
The veterinarian is not running late for afternoon consults	0.510***	0.091	0.519***	0.090
Habit				
The farmer uses this antimicrobial the same time every year	ref		ref	
The farmer has never used the antimicrobial for this reason before	-0.565***	0.090	-0.580***	0.088
Willingness to pay				
Farmer does not want to pay for a veterinary visit	ref		ref	
Farmer says he is happy for a veterinary visit	-0.874***	0.090	-0.865***	0.089
Confidence				

The veterinarian is confident in the farmer's judgement of the disease	ref		ref	
The veterinarian is not confident in the farmer's judgement of disease	-1.752***	0.092	-1.752***	0.112
Practice type				
No small animal practice	ref		ref	
Yes small animal practice	-0.490*	0.243	-0.495*	0.244
Region				
South East England	ref		ref	
Northern Ireland	3.578***	0.532	3.616***	0.538
Scotland, North West England	1.345***	0.351	1.358***	0.352
Wales, Central, North East, and South West England	0.846*	0.335	0.852*	0.331
Agreeableness score				
<=4	ref		ref	
4.5-5.5	-0.407	0.262	-0.390	0.261
>=6	-0.626*	0.275	-0.618*	0.274
Intercept	6.289	0.416	6.297	0.419
Covariance (slope, intercept)			-0.728	0.248
DIC	10205.34		10125.73	
	Marginal	**Cond.**	**Marginal**	**Cond.**
R^2	0.240	0.495	0.241	0.538
VPC	0.335			
MAE	1.760		1.626	
N Vignettes	2281		2281	
N Respondents	287		287	

*p≤0.05; **p≤0.01; ***p≤0.001. SE = standard error; Cond. = conditional

Model 1B, a random intercept model for the respondents expected percentage of veterinarians who would prescribe (Outcome B), and Model 2B, including a random slope effect for the variable of veterinarians confidence in farmer's judgement, are presented in Table 21. Models for outcome B included the same variables with the same positive or negative associations as models for outcome A, as described above. However, "small animal practice" was removed from the model as it was no longer significant. Age was dichotomised at 31 years because just under half of the study population were under the age of 31. This variable for age was added to the models for outcome B as it was found to be significant, where "age ≥31 years" had a significant negative impact on percentage of veterinarians' ratings.

Table 21: Random slope and random intercept models to explain the percentage of veterinarians which respondents expected to prescribe antimicrobials in the vignette situations (Outcome B)

	Model 1B		Model 2B	
Outcome B	**B**	**SE**	**β**	**SE**
Case type				
Farmer suspects calf pneumonia	ref		ref	
Farmer suspects watery mouth	0.348**	0.110	0.327**	0.109
Farmer wants to prevent calf pneumonia	-0.672***	0.109	-0.696***	0.108
Farmer wants to prevent watery mouth	0.167	0.111	0.152	0.110
Farmer relationship				
The farmer is a client of 10 years and the veterinarian rarely visits the farm	ref		ref	
The farmer is a client of 10 years and the veterinarian regularly visits his dairy herd	0.551***	0.097	0.558***	0.096
The farmer has been a client for less than a year	-0.301**	0.094	-0.286**	0.093
Other veterinarians in practice				
No other veterinarian in the practice has prescribed the farmer this antimicrobial before without consultation	ref		Ref	
Other veterinarians in the practice have prescribed the farmer this antimicrobial before without consultation	0.572***	0.078	0.574***	0.078
Time pressure				
The veterinarian is running late for afternoon consults	ref		Ref	
The veterinarian is not running late for afternoon consults	0.355***	0.078	0.355***	0.078
Habit				
The farmer uses this antimicrobial the same time every year	ref		Ref	
The farmer has never used the antimicrobial for this reason before	-0.496***	0.078	-0.495***	0.077
Willingness to pay				
Farmer does not want to pay for a veterinary visit	ref		ref	
Farmer says he is happy for a veterinary visit	-0.544***	0.078	-0.544***	0.077
Confidence				
The veterinarian is confident in the farmer's judgement of the disease	ref		ref	
The veterinarian is not confident in the farmer's judgement of disease	-1.369***	0.079	-1.368***	0.090
Age				
<=30	ref		ref	

>31	-0.436*	0.186	-0.452*	0.188
Region				
South East England	ref		ref	
Northern Ireland	3.057***	0.471	3.043***	0.472
Scotland, North West England	1.159***	0.319	1.160***	0.320
Wales, Central, North East, and South West England	0.850**	0.305	0.855**	0.307
Agreeableness score				
<=4	ref		ref	
4.5-5.5	-0.741**	0.237	-0.749**	0.236
>=6	-0.699**	0.251	-0.710**	0.250
Intercept	5.911	0.365	5.936	0.368
Covariance (slope, intercept)			-0.219	0.167
DIC	9611.62		9573.39	
	Marginal	**Cond.**	**Marginal**	**Cond.**
R^2	0.217	0.504	0.217	0.531
VPC	0.366			
MAE	1.486		1.411	
N Vignettes	2298		2298	
N Respondents	289		289	

*p≤0.05; **p≤0.01; ***p≤0.001. SE = standard error; Cond. = conditional

Analysis showed that the DIC scores were lower for the random slope models, indicating improved model fit. The VPC for the models indicated that 33.5%-36.6% of variability in prescribing decisions was attributed to differences among veterinarians. R^2 values showed that the models explained 21-24% of variance. The negative covariance between the slope and intercept values indicated that veterinarians who were less likely to prescribe overall were more influenced by the “confidence in farmers’ judgement” variable.

From the results obtained from the models to explain the veterinarians' likelihood to prescribe antimicrobials, and the percentage of veterinarians which respondents expected to prescribe antimicrobials, a theoretical framework was produced using all significant factors (Figure 11).

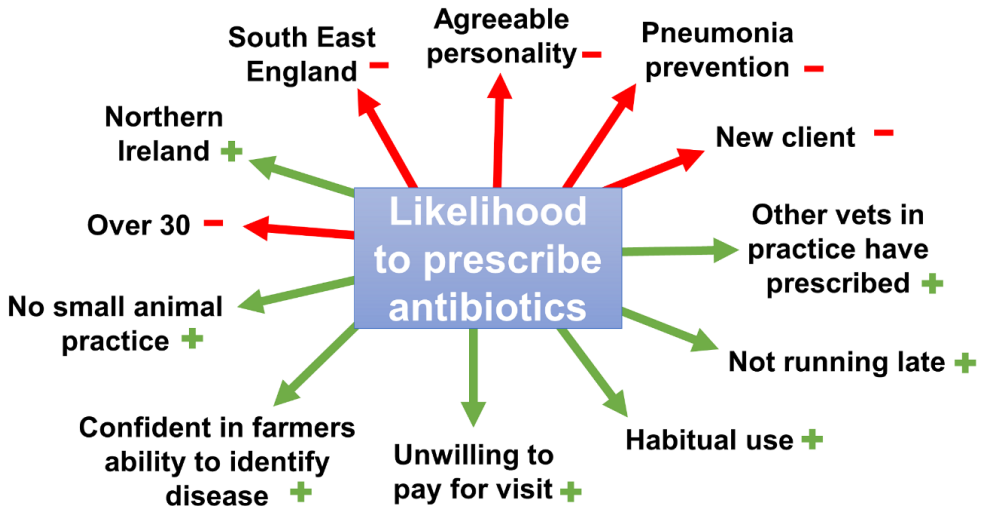


Figure 11: Framework obtained from the results of the survey with regards to significant factors associated with the decision to prescribe antimicrobials (+ and - signs indicate direction of associations) (p<=0.05).

5.5. Discussion

To the author's knowledge, this is the first and only study to date in veterinary decision-making that investigated (a) the impact of key constructs from multiple social theories on veterinarian decision-making; (b) the prescription decision of antimicrobials to both sheep and beef farmers; and (c) decisions around prescription in contexts other than clinical consultation. The novel aspect of this work is that it identified a range of different psychosocial factors that significantly influence the veterinarians' decision to prescribe antimicrobials. These factors could be considered as a framework for understanding and influencing veterinarian decision-making regarding antimicrobial prescription.

The most influential factor on the decision to prescribe was confidence in the farmer's judgement of disease. The results suggest that the impact of this variable was different among veterinarians i.e. veterinarians whose vignette ratings were largely influenced by the confidence variable will have a steeper slope. Similarly, Coyne et al (2018) identified confidence that farm staff would use antimicrobials responsibly as a positive driver for antimicrobial prescription by farm animal veterinarians. Morgan and Hunt (1994) theorised that trust and commitment were the heart of a successful business-client relationship. They highlight that as part of their commitment-trust theory, confidence is integral to the definition of trust. Whilst previous research identified the importance of farmers' trust in veterinarians (Jansen et al., 2010, Higgins et al., 2017), there has been little research into the importance of veterinarians' trust in farmers. This is an area which needs further investigation to fully understand how trust develops in this relationship.

In this study, farmer relationship was shown to be influential, as veterinarians were less likely to prescribe to a new client when compared to a long-term client. This factor was included to account for the commitment construct in the commitment-trust theory, where one of the drivers for commitment is the relationship termination costs (Morgan and Hunt, 1994). The results from this study suggests that veterinarians are committed to maintaining long-term relationships with their clients, and may prescribe to long-term clients at their request. Relationship with the client was a major influence of prescribing for pig veterinarians (Coyne et al., 2014, Coyne et al., 2016), and cattle veterinarians (Gibbons et al., 2013). However, this influence appeared to be due to perceived client demand, rather than maintenance of client relationship.

Veterinarians were more likely to prescribe when the farmer received regular veterinary visits. This may be because they have more recent knowledge of the condition of the animal or current health status of the herd or flock. In the UK, the farm animal veterinary profession is moving towards a more advisory role, where their work is oriented to managing herd and flock health, rather than treating sick individual animals (Ruston et al., 2016). In the scenario, regular veterinary visits may influence the decision to prescribe as it may suggest that a one-to-one relationship between the farmer and veterinarian exists.

The respondents were significantly more likely to prescribe, and also expected more veterinarians to do so, when the veterinarian in scenarios was not running late. This is contradictory to previous research in doctors prescribing behaviour – whereby doctors stated that they were more likely to prescribe antimicrobials when they were under time pressure (Björkman et al., 2011). This is because prescription can be used as a method to end the consultation faster (Lucas et al., 2015). One possible reason for this difference is because veterinarians were prescribing without having a clinical consultation. This study suggests that veterinarians may feel more comfortable prescribing antimicrobials to farmers if they have more time to discuss the matter with them. In a previous study, over 50% of cattle veterinarians stated that time pressure would have no effect on their prescribing behaviour (Gibbons et al., 2013). However, the previous survey used direct questioning, and so the less direct questioning in the current study possibly uncovered some bias in the previous study.

Respondents were significantly more likely to prescribe when another veterinarian in practice had prescribed to the farmer before. It is well known that in human medicine, doctors' prescribing decisions are heavily influenced by relationships with team members (Broom et al., 2016). The results of this study suggest that veterinarians may also succumb to similar prescribing norms. Indeed, it has previously been identified in pig practice that more

senior team members of the veterinary practice may pressurise junior members to prescribe antimicrobials to their “good” clients (Coyne et al., 2016).

Veterinarians were significantly more likely to prescribe if the farmer used that antimicrobial the same time every year. The two diseases used in the scenarios, watery mouth in lambs and calf pneumonia, tend to be seasonal, and farmers may stock up on antimicrobials around lambing or weaning time in calves. This may suggest that veterinarians are more likely to prescribe to farmers who have a habitual AMU behaviour, such as using antimicrobials for prevention. According to Triandis’ Theory of Interpersonal Behaviour, as the frequency of past behaviour increases, the level of consciousness on the decision to perform a behaviour decreases (Triandis, 1977). Thus, prescribing to habitual users of antimicrobials may become an automatic process.

When the farmer was not willing to pay for a farm visit, veterinarians were significantly more likely to prescribe. This is because a situational constraint has been placed on the veterinarian’s decision; a construct of the TPB called perceived behavioural control (Ajzen, 1991). With the veterinarian unable to visit the farm, they are relying on the farmer’s information and cannot carry out a clinical investigation before making the decision. The farmer’s decision will affect the veterinarian’s perceived ease or difficulty of performing a consultation before prescribing. Similar situational constraints on veterinarians’ decisions to prescribe identified from pig practice include farmers' management practices and willingness or ability to invest in prevention measures (Coyne et al., 2016).

This study revealed that the prescribing of antimicrobials for the prevention of watery mouth may still be a generally accepted practice by veterinarians, despite UK campaigns communicating that this should not the case (RUMA, 2017) . This may be because veterinarians are generally less confident working with sheep than cattle (Bellet et al., 2015, Kaler and Green, 2013), and spend more of their time with cattle. Consequently, veterinarians are probably more confident in the alternatives to antimicrobials available to control calf pneumonia, compared with watery mouth in lambs. The practice of prophylactic treatment of watery mouth in lambs is an example of potential avoidable use of antimicrobials, which may select for resistance.

As well as the vignette variables, four veterinarian or veterinary practice characteristics significantly influenced the decision to prescribe. Interestingly, those that rated themselves as more agreeable were significantly less likely to prescribe antimicrobials themselves, and expected fewer other veterinarians to do so. Agreeable people are perceived as more benevolent, sociable, and willing to engage in conversations with unfamiliar people which may allow for easier discussions of appropriate alternatives to AMU (Roccas et al., 2002). Additionally agreeableness increases with age (Roberts et al., 2005), as also

indicated in this study (p ≤0.001). With age, veterinarians would be expected to have increased confidence in prescribing behaviour. This may also be why age was significantly associated with the rating for the percentage of other veterinarians who would prescribe, but not with the likelihood to prescribe themselves. Less experienced or younger veterinarians could be more perceptive to norms, or they may think they are more prudent with their prescribing decisions than experienced veterinarians (Hopman et al., 2018), Respondents were significantly less likely to prescribe if their practice had a small animal department. To the author's knowledge, the influence of small animal practice on farm animal practice prescribing behaviour has not been identified before. AMU practice policies are no more prominent in small animal practice than in farm animal (Hughes et al., 2012). It is possible that the variation is simply due the social influence of the different management practices.

Overall, this study identified some areas for improvement in veterinary prescribing behaviour, such as prescribing for the prevention of watery mouth, or prescribing habitually. With new EU regulations on veterinary medicines coming into place in 2022 (The European Parliament and Council of the European Union, 2019), veterinarians must be more stringent with their antimicrobial prescribing. For example, prescribing antimicrobials for prophylactic treatment will not be allowed except in exceptional circumstances. Additionally, prescribing antimicrobials for routine treatments or to compensate for poor animal management will not be allowed. Therefore, veterinarians will need to carefully consider how producers will use the antimicrobials they ask for. On the other hand, the study identified areas where veterinary prescribing behaviour was optimal, such as prescribing to farms which have regular visits and prescribing when not under time pressure and importance of farmer veterinarian relationship in facilitating this. This may highlight that farm animal veterinarians have recently developed a more advisory role on farms, rather than just being present in emergencies. Further research is needed on how trust is built and how veterinarians determine confidence in farmer diagnoses.

5.5.1. Strengths and limitations

This study is novel in its use of a factorial survey approach to measure veterinarian decision-making. The advantage of this method is that it reduces the confounding of social desirability bias by forcing respondents to make trade-offs without direct questioning. This is evident from the results for the variable of case type, where there was no significant difference in the respondent's ratings for cases of suspected calf pneumonia or for the prevention watery mouth in lambs.

The factorial survey approach improves the validity of the study by combining experimental design with survey methods. Applying survey methods means

that a broader respondent population can be reached compared to experimental or qualitative research, allowing the results to be more generalisable; therefore increasing external validity. In addition, the experimental design of random allocation of vignettes to respondents increases internal validity.

A limitation of this study is that only a quarter of variability in the decision-making was explained by the factors explored, suggesting the possibility of other unexplored factors influencing the decision. This is not uncommon in behaviour research as the most commonly used theory, TPB, tends to explain 19.3% of variability in a behaviour (McEachan et al., 2011). Various cross-validation and multiple model checks showed that models were robust.

Veterinarians who answered this survey were on average younger than those who responded to the large-scale Survey of the Veterinary Profession (Buzzeo et al., 2014). However, many of the demographics, such as gender and role proportions, were similar. Though there were regional prescribing differences, care must be taken when interpreting these results as a small number of responses were received from Northern Ireland, so unlikely to be a representative sample. Nevertheless, this study has one of the largest sample sizes for research into UK veterinarian decision-making regarding antimicrobials to date.

5.6. Conclusion

In conclusion, this is the first study to measure the relative importance of factors on veterinarians' decisions to prescribe antimicrobials in contexts other than clinical consultation, as well as the first study to measure veterinarian prescribing decisions to sheep and beef farmers. Social theoretical constructs such as habit, social influence and trust; veterinarian, and veterinary practice characteristics all had an influence on the decision to prescribe. These influential factors could be considered in intervention studies aimed at improved antimicrobial stewardship in beef and sheep veterinary practice. Further research is needed on how trust is built and how veterinarians determine confidence in farmer diagnoses.

6. Study 4: AMU practices and perceptions of beef farmers in England and Wales

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Author contributions:

CH, RB and JK created the survey. FL contributed to the study design. RB and CD had roles in data curation CD conducted formal analysis, investigation, methodology, project administration, visualisation and writing (original draft). JK and CH supervised the analysis. All authors participated in writing (reviewing and editing).

6.1. Abstract

Limited research exists on AMU practices of beef farmers. This study aimed to investigate antimicrobial practices and perceptions of beef farmers in England and Wales, and identify drivers for higher AMU for the treatment of bovine pneumonia. A survey was sent out in 2017 to beef farmers in England and Wales who supplied to two abattoirs. Descriptive statistics were used to summarise the data. A logistic regression model was built to determine factors associated with treating >5% of the predominant group in the herd with antimicrobials for pneumonia. There were a total of 171 useable responses. Most farmers reported using antimicrobials in <5% of their herd for the treatment of common diseases. Most farmers (90%) reported that they understood what AMR means, but only 55% were aware of critically important antimicrobials and 8% could name at least one critically important antimicrobial. Having a calf rearing enterprise and not considering Johne's disease when buying in cattle were associated with using antimicrobials to treat pneumonia in >5% of the predominant group in the herd. Self-reported AMU appears to be low in beef farms. However, some gaps in understanding aspects of antimicrobial stewardship by farmers were identified.

6.2. Introduction

As a result of the emergence of AMR as a global public health threat, there have been many recommendations towards the responsible use of antimicrobials, both in human and veterinary medicine (O'Neill, 2016). Examples in veterinary medicine include limiting the use of antimicrobials

prophylactically, restricting the use of high-priority CIAs and the use of surveillance systems to monitor AMU (RUMA, 2017, Speksnijder et al., 2015c).

Despite the growing pressure of ensuring prudent use of antimicrobials, there are few data on how antimicrobials are used in the UK beef sector (RUMA, 2017). Reasons for this lack of data include the difficulty to distinguish between dairy and beef herds using sales data, the sheep and beef industries being highly interlinked, and the large variation between types of beef enterprises. Furthermore, veterinary prescription data may not correspond to what is actually used on the farm as farmers often keep stocks of antimicrobials in order to identify and treat disease themselves without veterinary supervision. The limited data available from the UK-VARSS report suggests that beef herds may be higher users of antimicrobials than dairy herds (VMD, 2020b). However, the UK-VARSS report does not state how AMU was collated or how AMU was distinguished between dairy and beef cattle, or sheep and beef cattle. Therefore, it is unknown how reliable the data are. Whilst the quantification of antimicrobials used in the UK beef sector remains difficult, information on how beef farmers are using antimicrobials could be collected. For example, Brunton et al. (2012) reported the most frequently used types of antimicrobials and prophylactic treatment practices by UK dairy farmers. This type of information is not yet available for UK beef farmers.

To ensure responsible AMU in the beef sector, further understanding on why farmers use antimicrobials is needed. Whilst the opinions of UK dairy and pig farmers on various aspects of AMU have been studied (Coyne et al., 2014, Jones et al., 2015), to the author's knowledge there are no studies of UK beef farmers. Beef farms are typically more extensive than dairy or pig farms and therefore the perceptions and opinions on AMU and AMR of beef farmers may differ from what has previously been reported with pig and dairy farmers.

The aim of this study was to investigate the AMU knowledge, practices, and opinions of beef producers in England and Wales, and identify drivers for higher AMU for the treatment of pneumonia. It was hypothesised that certain management practices and farm characteristics were associated with AMU.

6.3. Methods

6.3.1. Survey design

The survey was designed by JK, CH, and RB. Both an online and paper-based version of the survey were created. The online survey was produced using the Smartsurvey™ platform and the paper version was produced using Microsoft Word. The survey was pilot tested on ten beef farmers and from their feedback, changes were made to some questions to improve clarity. The pilot surveys were not included in the final dataset. It was estimated that the survey would take around 20-25 minutes to complete. The survey was open

from November 2017 to April 2018 and respondents were asked about their practices over the past twelve months. A copy of the survey is presented in Appendix 6.

All respondents were required to answer sections on farm demographics, cattle health, AMU practices, and opinions on AMU and AMR. However, as some questions were not relevant to some enterprise types, respondents were not forced to answer every question. Hence, there were different response numbers for questions. There were 85 questions in total. The majority of questions were either nominal or ordinal with thirteen open-ended questions. An outline of the survey sections relevant to this study is provided below.

6.3.1.1. Farm demographics

This section included general questions such as geographic location of farm, other enterprises on the farm and type of production system.

6.3.1.2. Cattle health

In this section respondents were requested to rate common health problems on a 1-5 scale, where one was a significant health problem and five was not a health issue at all. A not applicable option was available.

6.3.1.3. AMU questions

Sections were included for respondents to describe their AMU for pneumonia, lameness, scour, joint ill, and mastitis over the last twelve months. A free text response was required for the most common antimicrobial product used for each disease. Respondents were also asked the most common group of cattle treated with antimicrobials, the proportion of cattle in this group treated with antimicrobials, and how they used antimicrobials. Respondents could select from prevention of disease, as a group treatment in an outbreak situation, or as individual treatments.

6.3.1.4. Opinions on AMU

The section consisted of a series of statements related to AMU or resistance based on previous research on dairy farmers' opinions (Jones et al., 2015, Swinkels et al., 2015). The respondent's level of agreement with the statements was measured on a 5-point Likert scale from "Strongly Disagree" to "Strongly Agree". A don't know response was available.

Respondents were also asked how their AMU has changed, and how they expect their AMU to change in the next three years and to compare their AMU to other similar enterprises. They were also asked about their awareness of CIAs, and sources of information about AMR.

6.3.2. Ethics

Farmers were informed that the anonymised data generated from this survey were to be used and published for research purposes. Participation was

voluntary and informed consent was gathered at the beginning of the survey by farmers agreeing to continue with the survey.

The study was approved by the University of Nottingham School of Veterinary Medicine and Science Ethics Committee (no 1850 160916) (Appendix 2).

6.3.3. Survey distribution

The target population were all beef farmers in England and Wales. The sample population was farmers in England and Wales who supplied beef cattle to a British retailer through two abattoirs. Therefore, the inclusion criteria for this survey was beef producers whose contact details were available to two abattoirs that supplied beef to one British retailer. Four hundred farmers were approached by one abattoir and 150 farmers were approached by the other abattoir. This represents 1.6% of the beef farms in England and Wales (AHDB, 2018a). The British retailer distributed the survey to farmers via a link to the online survey through email. Farmers who said that they did not have good internet access through phone communication with abattoir staff were sent a paper copy of the survey through the abattoir processors. Some responses were collected by abattoir staff by asking farmers to complete the survey when they brought their cattle in to the abattoir. Reminders to non-responders were sent by email via the abattoirs.

6.3.4. Data analysis

Data cleaning, descriptive statistics and logistic regression were carried out in Stata 15.1 (Stata SE/15.1, Stata Corp., College Station, TX, USA). If there were duplicate entries from the same farm, the most complete response was kept for analysis. The responses to the open-ended questions in the cattle health section "Which antimicrobial product do you most commonly use for …?" were categorised into the antimicrobial classes. Any answers which were not antimicrobials were removed from analysis. For descriptive analysis of numeric variables, the median and interquartile ranges were calculated and for categorical variables, contingency tables were produced.

6.3.5. Multivariable logistic regression

The dependent variable of interest was the proportion of the most commonly treated group in the herd treated with antimicrobials for pneumonia in the past twelve months. Respondents could select the breeding herd, pre-weaned calves, store cattle less than one year old, or store cattle more than one year old as the group of animals they most commonly treat for pneumonia. Then respondents were asked what proportion of this group were treated for pneumonia. Respondents could select <5%, 5-15%, 15-50% or >50%. The majority of respondents (71%, 99/139) selected <5%. For modelling purposes a binary variable that was dichotomised at 5% of the most commonly treated group in the herd treated with antimicrobials for pneumonia was created.

Initially, a univariable analysis was carried out and a Benjamini-Hochberg adjustment procedure was run with a false discovery rate of 0.1 to avoid type I errors (Appendix 7) (Benjamini and Hochberg, 1995). A false discovery rate of 0.1 was used as a similar analysis had not been conducted before and therefore this was the first, exploratory step in the research (McDonald, 2014). Variables considered for analysis were those that (1) were potentially relevant to the dependent variable and (2) were answered by the majority of respondents. Significant variables were considered for multivariable analysis. A forward selection stepwise model building approach was used to assess for confounding, where only variables with p≤0.05 were selected to remain in the model. Potential interaction terms were investigated by adding them into the model. The multivariable logistic regression model took the form of:

$$over\ 5\%\ treated_i \sim Bernoulli(mean = \mu_j)$$

$$\ln\left(\frac{\mu_i}{1-\mu_i}\right) = \alpha + \boldsymbol{\beta_i x_i}$$

Where $over\ 5\%\ treated_i$ is whether the ith farmer treated over 5% of the most common group in the herd with antimicrobials for pneumonia, μ_i is the fitted probability of the outcome, α is the intercept, and $\boldsymbol{\beta_i}$ is the vector of coefficients corresponding to the vector of predictor variables (calf rearing enterprise, most common group treated for pneumonia, comparison of AMU to others, consideration of Johne's disease, digital cattle movements and pneumonia health challenge rating), $\boldsymbol{x_i}$.

The Hosmer-Lemeshow test was carried out to test model fit. The variance inflation factor (VIF) and the tolerance was inspected for collinearity between variables.

6.4. Results

6.4.1. General farm characteristics

There were a total of 171 respondents, giving a response rate of 31%. Of the 171 respondents, 72 had a suckler herd, 42 had a calf rearing herd and 124 had a growing and finishing herd as part of their enterprise. Almost half of farmers were aged between 46-65 (48%, 82/171), 30% (50/171) were aged between 26-45, 17% (29/171) were over 65 and 5% (10/171) were under 25 years old. Additionally almost half of farms were based in the West Midlands (48%, 81/171), 22% (37/171) were in Northern England, 19% (33/171) were in Wales, and 11% (19/171) were in the South or Eastern England. The majority of farms also comprised of a sheep enterprise (64%, 110/171).

6.4.1.1. Suckler herds

Of the 72 enterprises with suckler herds, the median number of suckler cows in the herd was 65 (IQR=32, 90). The median suckler target finishing age was 20 months (IQR=18, 24).

6.4.1.2. Calf rearing herds

The median number of dairy calves bought annually was 85 (IQR=50, 170). The median dairy target finishing age was 22 months (IQR=19, 25).

6.4.1.3. Finisher herds

The median annual number of weaned calves (less than 1 year old) bought was 60 (IQR=25, 100). The median number of store cattle (greater than 1 year old) bought was 150 (IQR=55, 430). The target finished age for finisher cattle was 24 months (IQR=21, 27.5).

6.4.2. Cattle health

The main source of information and advice on the health of cattle for 74% of farmers was their local veterinarian (119/159). Table 22 shows how respondents rated health issues in terms of challenges to their herd, where 1 is significant health issue and 5 is not a health issue at all.

Table 22: Beef farmers' ratings for health issues in terms of challenges to their herd (1=Significant health issue, 5=Not a health issue at all)

Health problem	N[a]	1	2	3	4	5
Pneumonia	170	25.90%	14.10%	27.10%	18.20%	14.70%
Liver fluke	164	15.20%	15.20%	22.00%	24.40%	23.20%
Worms	162	11.70%	14.20%	31.50%	22.20%	20.40%
Fertility	79	10.10%	5.10%	17.70%	34.20%	32.90%
Coccidiosis	118	8.50%	6.80%	15.30%	24.60%	44.90%
Lameness	167	8.40%	12.00%	22.20%	38.90%	18.60%
Navel/joint ill	111	7.20%	7.20%	9.00%	21.60%	55.00%
Mastitis	87	6.90%	6.90%	17.20%	36.80%	32.20%
Diarrhoea calves under 1 month	104	6.70%	13.50%	16.30%	34.60%	28.80%

[a] Number of responses differs as some health problems were not applicable to all enterprise types

6.4.2.1. Antimicrobial management of pneumonia

Only 1% (2/145) reported using antimicrobials as a preventative measure for pneumonia (prophylaxis), and 1% used antimicrobials as a group treatment following an outbreak of pneumonia (metaphylaxis). The most common group of cattle treated with antimicrobials was relatively evenly distributed between store cattle less than 1 year old (37% 52/139), pre-weaned calves (37% 51/139) and store cattle over 1 year old (26% 36/139). Twenty-eight percent of farms reported treating over 5% of the group that they most commonly treat with antimicrobials for pneumonia (40/139). The antimicrobial classes that were most commonly named by farmers for the treatment of pneumonia are presented in Figure 12. There were eleven farmers who named either vaccines or anti-inflammatories instead of an antimicrobial and therefore their answers were excluded from the analysis of this section.

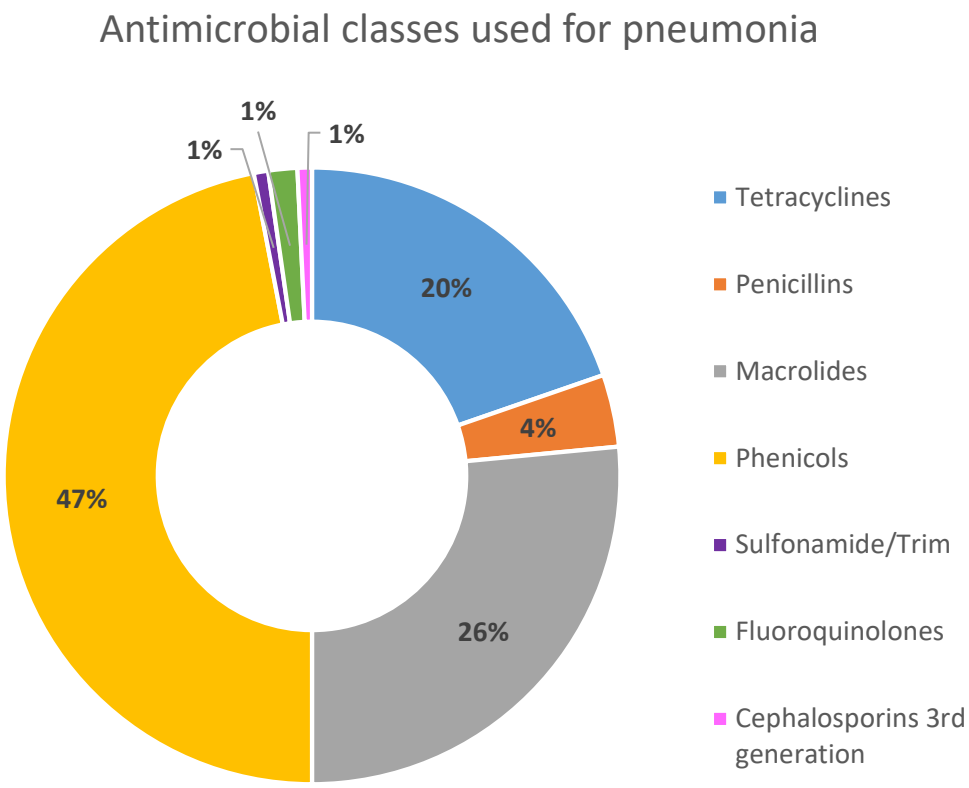


Figure 12: Antimicrobial classes most commonly used by beef farmers for the treatment of pneumonia (N=132)

6.4.2.2. Antimicrobial management of diarrhoea

Calf diarrhoea was relevant to 64 farms who responded to the survey. Antimicrobials were reportedly used to treat sick individual animals on 95% (61/64) of farms. Sixteen percent (8/63) of farms reported treating over 5% of their most commonly treated group with antimicrobials for calf diarrhoea. Penicillins were the most common antimicrobial class used to treat calf diarrhoea (65%, 36/55). There were sixteen farmers who named treatments which did not contain antimicrobials and therefore were excluded from descriptive analysis of this section.

6.4.2.3. Antimicrobial management of other diseases

Five percent (3/57) and 4% (2/55) of farmers reported treating over 5% of their breeding herd with antimicrobials for calving related disease and mastitis, respectively. Seven percent (5/72) and 8% (11/142) of farmers reported treating over 5% of cattle in the predominant group in the herd with antimicrobials for joint ill and lameness, respectively. None of the respondents reported the use of CIAs for treatment of calving related disease, mastitis, lameness or joint ill.

6.4.3. Knowledge, opinions and perceptions around AMU and AMR

Over half of farmers were aware of CIAs (55% 93/169). Only 9% (15/169) of farmers were able to name at least one CIA listed by the EMA. A small number of farmers thought that their AMU had increased in the past three years (4% 6/168), 37% (62/168) thought that their AMU had remained roughly the same, and 59% (100/168) thought that their AMU had reduced. The majority of respondents expect that their AMU will remain roughly the same in the next three years (62% 104/168); whilst 37% (63/168) of respondents expect that their AMU will reduce.

The main source where farmers had heard of AMR in the past twelve months was print or other media (74%, 126/171). Under half of respondents had heard about AMR from their veterinarian (44%, 75/171).

Just over half of farmers thought they had the support they needed to reduce AMU in their beef enterprise (52% 86/166), 31% were not sure and 17% thought they did not have the support they need. When asked what additional support would help to reduce AMU in their beef herd, 42% would have liked more information on disease control (71/171), 41% would have liked more information on different types of antimicrobial (70/171), 29% would have liked one-to-one advice on reducing disease in their herd (49/171), 25% would have liked clearer messages about goals on AMU (43/171) and 20% would have liked benchmarking data on AMU in beef enterprises (35/171).

6.4.4. Antimicrobial opinion statement ratings

Just under 40% (66/166) of farmers agreed that antimicrobials were beneficial to prevent diseases in their herd. Almost a quarter of farmers agreed that it is acceptable to use antimicrobials to prevent disease in animals (24% 40/166). Almost ninety percent (149/166) of farmers believed that they understood what AMR means. Table 23 presents the ratings of each antimicrobial statement.

Table 23: Beef farmers' views on a series of statements related to AMU and AMR

Statement	N	% Strongly agree or agree	% Neutral	% Strongly disagree or disagree	% Don't know
Use of antimicrobials is beneficial to prevent disease in my herd	166	39.8	15.6	40.4	4.0
Use of antimicrobials is beneficial to maximise productivity of my herd	166	34.9	15.7	45.8	3.6
Use of antimicrobials is beneficial to the welfare of my herd	166	66.3	20.5	10.8	2.4
It is ok to use antimicrobials to treat sick individual animals	166	93.4	0.0	4.2	2.4
It is ok to use antimicrobials to prevent disease in animals	166	24.1	16.9	53.6	5.4
Society thinks farmers use too much antimicrobials	166	56.0	19.9	10.2	13.9
Using less antimicrobials makes me a good farmer	166	41.6	27.1	19.3	12.1
I understand what AMR means	166	89.7	3.6	3.6	3.0
Preventative use of antimicrobials can contribute to AMR	166	71.1	9.0	6.6	13.3
Curative use of antimicrobials can contribute to AMR	166	34.9	22.3	26.5	16.3
The use of antimicrobials in animals can contribute to AMR in people	166	48.8	19.3	10.2	21.7
Reduction in the use of antimicrobials could be achieved with better management or vaccines	166	72.3	12.7	7.8	7.2
If every beef farmer followed best practice, there would be less resistant bacteria	166	39.2	22.3	17.5	21.1
I have the skills and knowledge needed to reduce antimicrobials in my herd	166	41.8	25.9	10.2	12.1
Reducing the use of antimicrobials in my herd over the next year would be difficult	166	43.4	27.1	21.8	7.8
Reducing AMU in my herd would have costs	166	44.0	22.9	21.7	11.5

6.4.5. Multivariable logistic regression

A multivariable logistic regression model was built to estimate the associations of farmer practices and opinions on treating over 5% of the most

common group in the herd with antimicrobials for pneumonia. The results are presented in Table 24.

Table 24: Results of multivariable logistic regression for treatment of over 5% of the herd with antimicrobials for pneumonia (N=129)

	N	Odds Ratio (95% CI)	p-value
Most common group treated for pneumonia			
Not pre-weaned calves	81	Ref	
Pre-weaned calves	48	14.16 (3.41, 58.83)	<0.001
Enterprise type			
Not calf rearing enterprise	95	Ref	
Calf rearing enterprise	34	5.20 (1.41, 19.14)	0.013
Compare AMU			
AMU the same or higher than similar enterprises	51	Ref	
AMU less than other enterprises	78	0.29 (0.05, 0.88)	0.041
Consider Johne's disease			
Sometimes or always consider Johne's	92	Ref	
Never consider Johne's	37	5.09 (1.31, 19.14)	0.019
Collect cattle movements digitally			
Yes	100	Ref	
No	29	4.55 (1.13, 18.26)	0.033
Pneumonia health challenge			
Health problem (Score 1-2)	56	Ref	
Not a health problem (Score 3-5)	73	0.27 (0.09, 0.83)	0.023
Intercept		0.21 (0.06, 0.81)	0.23

The Hosmer-Lemeshow test gave a p-value of 0.5, indicating that the model fit the data well. The VIF and tolerance values of the variables used in the logistic regression indicated that there were no collinearity problems.

6.5. Discussion

This study provides insight on AMU practices of beef farms in the England and Wales. To the author's knowledge it is the first study in the UK to present the opinions of beef farmers towards AMU and resistance and to report drivers for increased AMU for the treatment of pneumonia. Most farmers reported that they treated less than 5% of the herd with antimicrobials for common health problems, suggesting that AMU was low. This is perhaps in contrast with the figures reported by VMD, where AMU in beef was higher than dairy (VMD, 2020b). Reasons for this disagreement could be due to the difference in study designs or that farmers in this survey under reported AMU due to social desirability bias (De Vaus, 2013).

One of the key findings in this study was that whilst few farmers reported using antimicrobials for prevention of disease, many farmers thought this was still appropriate practice. Around 24% of farmers thought that it was acceptable to use antimicrobials to prevent disease, and 40% thought that antimicrobials were beneficial to prevent diseases in their herd. The proportion of farmers who agreed with preventative AMU may be relatively high as in cases such as an outbreak of respiratory disease, it may be prudent to treat a group of animals before clinical signs are apparent (metaphylaxis). As respondents were only asked about preventative AMU, the authors were unable to distinguish differing opinions on metaphylactic and prophylactic AMU. The difference between attitudes towards prophylactic or metaphylactic AMU and actually carrying out the practice may be because farmers do not want to use antimicrobials for reasons such as cost, time, or that they do not think that the disease levels in their herd warrant such use. Farmers may think that antimicrobials would be beneficial for prevention of disease in their herd but do not undertake this practice as they are aware of the risks of AMR. Alternatively, farmers may not want to state that they use antimicrobials for prevention even when they do, as AMU in agriculture has had considerable attention over recent years (O'Neill, 2016). A further reason for this difference is that there may be multiple people employed on a farm and the person filling in the survey may have not known about the AMU in separate management groups over the twelve month period.

Most AMU tended to be for curative reasons with antimicrobial classes that are low risk to public health, such as penicillin and tetracyclines. The low use of third generation cephalosporins and fluoroquinolones may be why only 55% of farmers were aware of CIAs, and even fewer could name one. A slightly higher proportion (60%) of UK pig farmers were aware of CIAs (Coyne et al., 2019). Although beef farmers seem to be low users of CIAs, it is still important to improve the awareness levels in case their veterinarian prescribes them CIAs in the future.

Most farmers (90%) said that they understood what AMR means. A similar level of understanding was reported by UK dairy farmers (Higham et al., 2018). However, levels of reported understanding around AMR may not be true as Higham et al. (2018) demonstrated that only 55% of dairy farmers could give an accurate description of AMR despite most of them saying they understood what AMR means. In order to investigate whether this is also true for beef farmers their knowledge and understanding of AMR requires further exploration.

Many beef farmers may have already taken steps to reduce their AMU. Very few beef farms in this study were using antimicrobials for prevention of disease in their herd, with 63% reporting that they had reduced their AMU in the past three years. However, additional support for UK beef farmers may be

needed if further refinements in AMU are required as a lower proportion (37%) of farmers expected their AMU to reduce in the next three years. Indeed, only 52% of farmers thought they had the support they needed to further reduce their AMU. Antimicrobials on farm must be prescribed by the veterinarian who has the animals 'under their care' (RCVS legislation). In practice, the veterinarian does not attend every animal that requires antimicrobials but develops a relationship with the farmer and establishes protocols that the farmer follows. This survey shows that under half the farmers had heard about AMR from their veterinarian. This may be because there is often a lack of contact between the veterinarian and beef farmer (Lowe, 2009), and previous work has identified that farmers may be unwilling to have regular veterinary visits to their farm (Kaler and Green, 2013, Ruston et al., 2016). The most commonly selected area where farmers would like more support around AMU reduction was more information on disease control, suggesting that some farms are unable to reduce their AMU further without compromising animal welfare. The veterinarian is best placed to give advice on reducing disease in their herd (Kaler and Green, 2013, Ruston et al., 2016). Clearly, this strategy necessitates all veterinarians understanding good practice and delivering appropriate advice with a proactive relationship between the veterinarian and farmer. Although veterinarians have an essential role in ensuring good antimicrobial stewardship, barriers to a proactive relationship between veterinarians and farmers need to be tackled first.

Sixty-four farms were using antimicrobials for the treatment of calf diarrhoea. A further sixteen farmers indicated treatments other than antimicrobials when asked about the most common antimicrobial used to treat diarrhoea. These results illustrate two important findings. First, treatment of uncomplicated diarrhoea with antimicrobials is discouraged (Constable, 2004) though farmers in this study appear to be using them anyway. This may be because farmers only ask for their veterinarians' advice in complex cases and due to the lack of contact with the veterinarian in cases of uncomplicated diarrhoea, the farmer remains unaware that antimicrobial treatment is unnecessary. Second, some farmers were unable to distinguish between antimicrobials and other treatments such as endoparasiticides or anti-inflammatories. This has obvious important implications for potential inaccuracies in farmer-reported AMU.

To understand why some farms may have an increased need to use more antimicrobials than others, a logistic regression analysis was carried out to determine factors associated with reportedly treating over 5% of the most common group with antimicrobials for pneumonia. Pneumonia was chosen as it was the most important health issue reported in the survey and was a disease that covered the three enterprise types. Drivers for increased AMU for the treatment of pneumonia included having a calf-rearing enterprise and

pre-weaned calves being the most common group of cattle treated with antimicrobials. Type of production system was also identified as a driver for AMU in Tennessee cattle producers (Ekakoro et al., 2019). Having a calf-rearing enterprise may increase AMU as calves from a mix of farms are transported to a calf-rearing enterprise at a young age, which is a risk factor for development of bacterial pneumonia infection (Caswell, 2014). Indeed, a higher rating for pneumonia as a health challenge, which suggests a high prevalence of pneumonia within the herd, was also a driver for increased AMU.

It appears that some farmers are aware of how much antimicrobials they use compared to other farms, as those who thought their AMU was less than other similar enterprises were less likely to treat over 5% of the most commonly treated group with antimicrobials for pneumonia. Similarly, pig farmers who used more antimicrobials estimated their own usage as higher than other pig farmers (Visschers et al., 2016b).

Some management practices were associated with AMU. The practice of never considering Johne's disease when buying in cattle significantly increases the likelihood of treating over 5% of the herd with antimicrobials for pneumonia. This may be because a relaxed attitude to biosecurity is associated with other management decisions that increase the risk of pneumonia in calves.

The other management factor associated with proportion of herd treated with antimicrobials for pneumonia was use of digital cattle movements. Cattle movements were the most common information reported by farmers digitally, possibly because in the UK the recording and reporting of all cattle moving on or off the farm is mandatory. Use of electronic identification has previously been associated with lower lameness levels in sheep (Lima et al., 2018). The use of digital management tools may be associated with reduced disease levels within the herd and consequently in lower AMU.

6.5.1. Limitations

The sample was biased geographically due to the location of the two abattoirs represented. The number of herds was small but herd size large (AHDB, 2018a). Therefore, comparison of these results with those from other populations may not be appropriate. Despite this the associations reported in this study needs further investigation. The study results highlight the importance of farmer's beliefs regarding AMU and AMR and that these need to be understood and tackled before longer term changes can be seen in the industry.

There were no exclusion criteria for respondents in terms of the role they had on their farm. Therefore, some respondents may not necessarily be responsible for all the animal groups on their farm and not know all the

antimicrobial treatments given on their farm. Respondents may have interpreted the proportion of animals treated within the last twelve months differently.

As the information in the survey was self-reported, there may be some social desirability bias, particularly with sensitive topics such as inappropriate AMU which may be perceived as a socially "undesirable" behaviour (De Vaus, 2013). The survey was based on general health management rather than explicitly focusing on AMU, which should mean that the survey was not skewed towards farmers with a specific interest in AMU. Farmers may have difficulty recalling practices in the past twelve months so may be affected by recall bias. Questions were asked about management in the past twelve months and therefore the date of questionnaire completion was included in the logistic regression analysis to check if this had a significant effect on the dependent variable. Date was not statistically significant (p=0.93) so was not included in the final model.

6.6. Conclusion

The results of this study suggest that AMU in beef farms was low and the majority of farmers were using antimicrobials for curative reasons rather than for prevention of disease. Farmers' reported understanding of AMR was high but awareness of CIAs was relatively low and could be improved. Drivers for increased AMU were identified in the study, which may help veterinarians and farmers better understand how to improve antimicrobial stewardship within the beef industry.

7. Study 5: From the other perspective: Behavioural factors associated with UK sheep farmers' attitudes towards AMU and AMR

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Author contributions:

EL, FL and JK created the survey. EL and CD did data curation. CD did formal analysis, investigation, methodology, project administration, visualisation and writing (original draft). JK supervised the analysis. CH, FL and JK had roles in project supervision. All authors contributed to writing (reviewing and editing).

7.1. Abstract

Some sheep farmers continue to carry out traditional AMU practices despite new 'good practice' recommendations. The aim of this study was to group farmers depending on their attitudes around AMU and AMR, and determine the behaviours that are associated with the farmers in these groups. In 2017, a flock health survey was sent to British sheep farmers. K-means cluster analysis was used to identify groups of farmers with similar attitudes towards AMU and resistance. A multivariable logistic regression model was built to determine the associations between farmers' past behaviours and their antimicrobial attitude group. There were 461 responses. Two groups of farmers were identified based on their antimicrobial attitudes. Cluster 1 were defined as the "discordant" group who had positive views of using antimicrobials prophylactically and negative views of reducing AMU. Cluster 2 were defined as the "concordant" group who were positive about reducing AMU and had negative views about using antimicrobials prophylactically. Using antimicrobials in all lambs ($p<0.001$), using antimicrobials in all ewes ($p=0.011$), always trimming diseased feet ($p=0.001$), not using a computer to record information ($p=0.010$), not changing worming practices ($p=0.013$), and farmers' perceptions that their sheep flock did not make a financial loss in the past three years ($p=0.029$) were significantly associated with belonging to the discordant group. Talking to their veterinarian about AMU or the frequency of veterinary visits were not associated with antimicrobial attitude group. These results suggest that farmers who had discordant attitudes relating to AMU

carried out more traditional practices, which was strengthened by their positive perceptions of profitability.

7.2. Introduction

Although the sheep sector is thought to be a low AMU sector based on limited data available (RUMA, 2020), sheep production plays a significant role in the overall agricultural AMU figures for the UK and there are opportunities for improved antimicrobial stewardship. The majority of AMU within the sheep sector is for the treatment of lameness (RUMA, 2020). The five-point plan to control and reduce lameness within flocks is widely recommended to farmers by the sheep industry (Clements and Stoye, 2014). The plan advises practices including culling persistently lame sheep, vaccinating for footrot, prompt treatment with antimicrobials, and not trimming feet. These practices have been shown to reduce the lameness prevalence within flocks (Kaler and Green, 2009, Kaler et al., 2010, Winter et al., 2015, Prosser et al., 2019). However, the uptake of the five-point plan by farmers is very low (Prosser et al., 2019, Best et al., 2020). This may be because foot trimming was traditionally a best practice that has been embedded as a cultural norm of what a 'good farmer' does, which makes the behaviour resistant to change (Clifton et al., 2020, Green et al., 2020).

As highlighted in the RUMA reports, one of the "hotspots" where AMU could be reduced in the sheep sector is neonatal lamb diseases, such as watery mouth (colibacillosis) and joint ill (suppurative polyarthritis) (RUMA, 2020). Historically, the prophylactic use of antimicrobials in neonatal lambs to control watery mouth and joint ill was common practice but this is now actively discouraged (RUMA, 2020). In 2016, 31% of UK sheep farms surveyed were still using antimicrobials for prevention of disease in neonatal lambs (Lima et al., 2019).

The routine use of antimicrobials in pregnant ewes to prevent abortion is also considered to be a 'hotspot' for unnecessary use (RUMA, 2020). As vaccines are available for the most common causative agents, *Chlamydia abortus* and *Toxoplasma gondii,* AMU for the control of abortion is often deemed unnecessary (Essig and Longbottom, 2015). Management practices such as keeping a closed flock, buying from accredited sources, and isolating recently aborted ewes can also help to prevent the spread of abortion. Results from a 2007 survey suggested that 9% of sheep farmers in the UK used antimicrobials to control abortion (Longbottom et al., 2013). The characteristics of farms that use antimicrobials for prevention of either abortion or neonatal diseases is unknown and needs to be investigated further to understand why farmers continue to use antimicrobials prophylactically.

Most research into farmer AMU behaviour focusses on the way farmers' attitudes influence their behaviour (Jones et al., 2015, Kramer et al., 2017).

This is because many social-psychological theories, including perhaps the most utilised theory - the TPB - propose that factors such as attitudes and perceptions influence behaviour (Ajzen, 1991). Jones et al. (2015) used the TPB to identify dairy farmers' barriers and drivers for the intention to reduce AMU. Their results suggested that the strongest drivers to reduce AMU was belief that their social and advisory network would approve of them doing so, and their desire to reduce costs. Conversely a study of Dutch farmers showed that their referent beliefs were not associated with AMU, but level of knowledge around antimicrobials was (Kramer et al., 2017). One limitation of previous studies is that they only investigate the association between attitudes and a single behaviour. Focusing on a single behaviour may lead to biased assessments because behaviours often have several interdependencies (Hidano et al., 2018). One method of assessing the associations of multiple attitudes and behaviours at the same time is to cluster those with similarly held attitudes into groups and then assess the profile of these groups in terms of behavioural and structural characteristics (Gorton et al., 2008, Guillem et al., 2012).

There is evidence that the association between attitude and behaviour is bidirectional and that behaviours can influence attitudes. This is particularly the case for undesirable behaviours such as smoking (De Leeuw et al., 2008) and binge drinking (van der Zwaluw et al., 2013). Past behaviour is one of the origins of attitude formation and there is evidence that behaviour can influence attitudes more strongly than the reverse (Kroesen et al., 2017). Currently, social science research into farmers' AMU have concentrated on the influence of farmer attitudes on their AMU behaviour (Jones et al., 2015, Scherpenzeel et al., 2016, Kramer et al., 2017). However, traditional embedded practices such as prophylactic AMU and foot trimming are repetitive, habitual behaviours which occur year after year, and farmers will learn and adapt from their previous experiences. The relationship between behaviour and attitudes is not static. Consequently, it is reasonable to assume that previous behaviours may be associated with present attitudes. Previous studies around attitudes to antimicrobials have not explored this.

In this introduction multiple antimicrobial practices have been considered that farmers continue to carry out despite new 'good practice' recommendations. Therefore, it was hypothesised that farmers' attitudes around AMU and AMR were associated with their past management practices. The aim of this study was to group farmers depending on their attitudes around AMU and AMR and then determine the behaviours and characteristics that are associated with the farmers in these groups.

7.3. Methods

7.3.1. Survey design

The survey was developed as part of a larger project and was designed by EL, JK and FL, and the survey design has previously been described in detail (Lima et al., 2020). This study investigated a subsection of data on AMU which has not yet been explored. Therefore, this study will only refer to the sections used to explore associations with AMU attitudes. The survey included sections on farm characteristics, farmer demographics, flock health management, AMU practices, opinions on AMU and AMR. The respondents were asked to answer the questions relating to practices implemented between September 2016 and August 2017. Below is an overview of each section of the survey used to explore associations with antimicrobial attitudes. A copy of the survey is presented in Appendix 8.

7.3.1.1. Farmer and farm characteristics

This section included questions on the farmer's characteristics such as age, number of years farming sheep and level of education. The farm characteristics included number of mature ewes, production system type, and size of farm. Farmers were asked whether their sheep flock had made a profit, loss, or broken even over the past three years. They were also asked if they had changed any farm practices over the past three years.

7.3.1.2. Health and performance of the flock

Respondents were asked about their management practices related to lameness control. This included vaccination against footrot, time from observation to treatment of lame sheep, foot trimming, use of antimicrobial injection, use of foot spray, and separation of lame sheep.

Other questions related to health management and performance were worming of lambs and ewes, culling practices, and data recording practices. Frequency of advice from a veterinarian was included.

7.3.1.3. AMU practices

Farmers were asked about the proportion of lambs they treated with antimicrobials for the treatment and prevention of watery mouth, joint ill, and cases of ill lambs (e.g. pneumonia) in the lambing season between September 2016 and August 2017. They were asked about the type of antimicrobial given which included oxytetracycline injectable, white injectable (e.g. penicillins), other injectable, oral antimicrobials, and antimicrobial pills. Photographs and manufacturer names of antimicrobials were included in this section for clarification. Farmers were also asked about the proportion of ewes they treated with antimicrobials for the treatment or prevention of abortion, problems around lambing, lameness, general illness (e.g. pneumonia), and mastitis.

7.3.1.4. Opinions on AMU

Respondents were asked to rate a series of sixteen statements around attitudes toward AMU and resistance, from 1=strongly disagree to 5=strongly agree. A don't know option was also available to select. The statements were informed from the wider literature on attitudes towards antimicrobials (Jones et al., 2015, Swinkels et al., 2015, Etienne et al., 2017).

7.3.2. Distribution of survey

The distribution of this survey has been previously described in (Lima et al., 2020). The target population for the sheep survey were farms in the UK who supplied lambs to a British retailer through two abattoirs (n=830). The target farms were sent links to the online survey by the two participating abattoirs in November 2017. A reminder was sent to non-responders in early January 2018 before the survey closed at the end of January 2018.

7.3.3. Ethics

Farmers were informed that the anonymised data generated from this survey were to be used and published for research purposes. Participation was voluntary and informed consent was gathered at the beginning of the survey by farmers agreeing to continue with the survey.

The study was approved by the University of Nottingham School of Veterinary Medicine and Science Ethics Committee (no 1850 160916) (Appendix 2).

7.3.4. Data analysis

Data cleaning and data analysis including descriptive statistics, cluster analysis and logistic regression were carried out in Stata 16.1 (Stata SE/16.1, Stata Corp., College Station, TX, USA). Where there were duplicate entries from the same farm, the most complete response was kept for analysis. General descriptive results from this survey have previously been published (Lima et al., 2020). However, due to differences in the data cleaning and analysis requirements, this study uses a larger number of respondents. Therefore, the descriptive results are reported again in case of differences in the sample population.

7.3.4.1. Cluster analysis

Cluster analysis was performed to identify groups of farmers with similar attitudes towards AMU and resistance. The farmers were grouped based on their ratings of the sixteen statements relating to AMU and resistance, from 1 (strongly disagree) to 5 (strongly agree). A small proportion (0.7-5.4%) of "don't know" responses were reported for nine statements. Any “don't know” responses were recoded as 3 (neutral) for cluster analysis. Cluster analysis was also run with the "don't know" responses removed and there was no significant differences in the results. Therefore, the set of responses with "don't know" coded as neutral were used as less respondents were removed

from the analysis. Four respondents were removed at this stage because of missing ratings for the statements.

For the cluster analysis, the assumption was made that a 5-point Likert scale could be treated as an interval scale. Some researchers argue that Likert scales cannot be considered as interval scale measurements and should be analysed as ordinal measurements. This is because the difference between each point on the scale cannot be considered equal (Jamieson, 2004). Researchers also argue that parametric tests cannot be used because Likert scales violate normality assumptions (Chen and Liu, 2021). However, in practice Likert scales are commonly treated as an interval scale (Subedi, 2016). The development and validation of rating scales often relies on parametric methods such as factor analysis and item response theory (Harpe, 2015). Research shows that modifying the distance on ordinal scales has a minimal effect on the outcome (Labovitz, 1970; Baggaley and Hull, 1982). Norman (2010) goes further to argue that parametric tests can be used on both Likert items and scales because parametric tests are robust to violations in normality assumptions.

It has been suggested that the confusion around the treatment of a Likert scale as ordinal or interval comes from misunderstandings around Likert items and Likert scales (Harpe, 2015). A Likert item is a single statement or question whereas a Likert scale is a series of statements that are combined into a single variable through data analysis (Subedi, 2016). A series of Likert items that are rated together must be analysed as a group because of the interrelationship among those items. In the social sciences – including veterinary social sciences – it is common for attitude ratings to be grouped together through cluster analysis (Thompson et al., 2015; Beer and Theuvsen, 2019; Regan et al., 2021; Rübcke von Veltheim and Heise, 2021). Research suggests that clustering raw data is superior to pre-processing the data with factor analysis and then running cluster analysis (Dolnicar and Grün, 2008).

K-means clustering uses an iterative algorithm to partition *n* observations into *k* clusters. A limitation of k-means cluster analysis is that the number of clusters must be defined *a priori* (Dunn et al., 2018). Therefore, hierarchical cluster analysis using Ward's method was carried out initially. A dendrogram was produced to estimate the optimum number of clusters (Haldar et al., 2008). This estimate was then used as the prespecified number of clusters in K-means cluster analysis. The Euclidian distance measure was used to determine the dissimilarity between observations. Sensitivity analyses was carried out using different clustering solutions to ensure the appropriate number of clusters was determined. The optimum number of clusters was two, as this achieved distinct clusters with similar group sizes and were easily interpretable upon inspection. The clusters were labelled based on their attitude alignment with current AMU recommendations.

7.3.4.2. Multivariable logistic regression

The dependent variable of interest was the antimicrobial attitude cluster group, where 1 was the discordant group and 0 was the concordant group. Potential independent variables were those relating to past and current management practices. New variables were created for past practices by inspecting farmers' responses relating to changes in management practices. If farmers selected that they had not changed any practices over the past three years, then it was assumed that the practices stated by farmers in the survey were carried out for the past three years. A univariable analysis was carried out and a Benjamini-Hochberg adjustment procedure was run with a false discovery rate of 0.1 to avoid type I errors (Appendix 9) (Benjamini and Hochberg, 1995). A false discovery rate of 0.1 was used as a similar analysis had not been conducted before and therefore this was the first, exploratory step in the research (McDonald, 2014). Significant variables were considered for multivariable analysis

For the multivariable analysis, a forward selection stepwise model building approach was used, where only variables with p≤0.05 were selected to remain in the model. The multivariable logistic regression model took the form of:

$$cluster\ group_i \sim Bernoulli(mean = \mu_j)$$

$$\ln\left(\frac{\mu_i}{1-\mu_i}\right) = \alpha + \boldsymbol{\beta_i x_i}$$

Where $cluster\ group_i$ is the antimicrobial attitude cluster group the ith farmer belongs to, μ_i is the fitted probability of the outcome, α is the intercept, $\boldsymbol{\beta_i}$ is the vector of coefficients corresponding to the vector of predictor variables $\boldsymbol{x_i}$.

The Hosmer-Lemeshow test was carried out to test model fit. The VIF and the tolerance were inspected for collinearity between variables. K-fold cross validation of the area under the curve (AUC) was implemented to estimate the performance of the model and facilitate model selection (Luque-Fernandez et al., 2019). The model with the highest mean AUC was chosen.

7.4. Results

A total of 461 usable responses were received, resulting in a 55.5% useable response rate. Of the respondents, 43.7% (200/461) were aged between 36 and 55, 40.8% (187/461) were aged over 55 and the remaining 15.5% were under 35 years old (71/461). Most farmers housed their sheep at lambing time (71.6%, 330/461).

The median flock size of farms was 520 (IQR 300-830), and the median grassland area used for sheep was 258 acres (IQR 150-480). Three quarters of

sheep farmers also kept beef cattle (75.5%, 248/461). The characteristics of the farm and farmer are presented in Table 25.

Table 25: Characteristics of the respondents and their farms

Characteristic	Percent (N)		
Age of farmer (years)			
Under 35	15.5% (71)		
36-55	43.7% (200)		
Over 55	40.8% (187)		
Highest qualification			
Secondary school	39.9% (184)		
Technical college	43.2% (199)		
University	16.9% (78)		
Flock type[a]			
Lowland	36.9% (170)		
Upland	53.8% (248)		
Hill	28.6% (132)		
Inside lambing			
Yes	71.6% (330)		
No	28.4% (131)		
	Median	**25% IQR**	**75% IQR**
Number of mature ewes	520	300	830
Grassland area used for sheep farming (acres)	258	150	480
% time spent working with sheep	50	35	70
Number of full time staff	1	0	2
Number of mature cows (beef)	18	0	50
Number of other cattle (not including dairy)	40	0	90

[a] Respondents could select more than one choice

7.4.1. Flock productivity

Over the past three years, 11.7% (54/461) of farmers thought that their sheep flock made a financial loss, 33.4% (154/461) thought they were at breakeven point and 45.3% (209/461) thought that they made a profit.

7.4.2. Changes in management practices

Over the past three years, 53.4% (246/461) of farmers had not changed any management practices on their farm, 21.3% (98/461) had made changes to their culling practices, 18.7% (86/461) had made changes to their recording practices, 26.3% (121/461) had made changes to their worming practices, and 17.1% (79/461) had made other changes to their management practices.

To investigate the changes in worming practices further, chi-squared tests were conducted to identify differences in worming practices between those who changed their practices and those who did not. A chi-squared test indicated that the proportion of farmers using faecal egg counting to judge whether lambs needed worming was significantly different for farmers who had changed their worming practices compared to those that had not ($\chi^2(1, N = 457) = 66.175$, $p<0.001$).

7.4.3. Flock advice

In the period September 2016 to August 2017, 6.5% (30/461) of farmers never sought advice about their flock from a veterinarian, 29.3% (135/461) sought advice just once, and 64.2% sought advice at least quarterly (296/461).

7.4.4. AMU practices and perceptions

Just over half of farmers reported that they had talked about AMU with their veterinarian between September 2016 and August 2017 (51.4%, 237/461), and just over a quarter reported that they had talked about AMR with their veterinarian (26.7%, 123/461). Many farmers reported that they had not talked about either AMU or AMR with their veterinarian (41.9%, 193/461).

Only 2% (9/461) of farmers thought their AMU was higher than usual between September 2016 and August 2017. Most farmers thought their AMU was roughly the same as usual (68.8%, 317/461), and the remaining 29.3% (135/461) of farmers thought their AMU was lower than usual.

Around half of farmers thought their AMU was less than other sheep farms (52.5%, 242/461). Most of the remaining farmers thought that their AMU was approximately the same as other sheep farms (46.9%, 216/461) and three farms thought their AMU was higher than other farms.

Twenty-two percent (102/461) of farmers used antimicrobials for prevention of watery mouth, joint ill, or general illness in all of their lambs, and 8.5% (39/461) of farmers used antimicrobials for prevention of disease in all ewes.

7.4.5. Antimicrobial attitude clusters

Respondents were clustered into two groups related to the rating of seventeen statements around AMU and AMR. The means of how each group rated the statements are presented in Table 26, where 1 represents “strongly disagree” and 5 represents “strongly agree”. There were particularly large differences in the mean ratings between the two clusters for statements relating to the use of antimicrobials for prevention of disease and the practicality of alternatives to the use of antimicrobials. The group of farmers in antimicrobial attitude cluster 1 tended to think that use of antimicrobials for prevention was acceptable and that use of antimicrobials was the only option for them, as alternatives were difficult or not feasible. Therefore, this cluster was named the "discordant group" because their attitudes did not align with current antimicrobial use recommendations. Farmers in antimicrobial attitude cluster 2 were more optimistic about alternatives to AMU and disagreed with using antimicrobials for prevention. This cluster was named the "concordant group".

Table 26: Mean ratings of antimicrobial statements for two clusters of farmers

	Antimicrobial attitude cluster 1 "Discordant group" Mean (SE)	Antimicrobial attitude cluster 2 "Concordant group" Mean (SE)
The use of antimicrobials is beneficial to prevent disease in my flock	3.811 (0.059)	2.162 (0.068)
The use of antimicrobials is beneficial to ensure productivity of my flock	3.712 (0.057)	2.776 (0.080)
The use of antimicrobials is beneficial to the welfare of my flock	4.223 (0.039)	3.868 (0.065)
In some flocks, dosing new born lambs with an oral antimicrobial is the only way to be sure watery mouth is prevented	3.674 (0.063)	2.785 (0.083)
It is ok to use antimicrobials to treat sick animals	4.450 (0.038)	4.518 (0.043)
It is ok to use antimicrobials to prevent disease in animals	3.772 (0.057)	2.254 (0.068)
Society thinks farmers use too many antimicrobials	3.408 (0.058)	3.842 (0.054)
The media provide a negative view of farmers regarding the use of antimicrobials	3.918 (0.053)	4.026 (0.055)
Using less antimicrobials makes me a good farmer	3.077 (0.065)	3.535 (0.065)
Preventative use of antimicrobials can contribute to AMR in sheep	3.704 (0.054)	4.329 (0.049)
Reductions in the use of antimicrobials could be achieved through better management	3.584 (0.056)	4.228 (0.051)
Alternatives to antimicrobials are not practical to implement	3.202 (0.054)	2.399 (0.059)
People I respect in the industry would approve of reducing the use of antimicrobials in my flock over the next year	3.292 (0.053)	3.518 (0.054)
Reducing AMU in my flock would have costs	3.622 (0.049)	2.899 (0.058)
Curative use of antimicrobials can contribute to AMR in sheep	3.155 (0.057)	2.785 (0.066)
If every sheep farmer followed best practice, there would be less bacteria resistance to antimicrobials in the human population	3.305 (0.054)	3.241 (0.067)
I have the skills and knowledge needed to reduce AMU in my flock in the near future	3.421 (0.045)	3.588 (0.047)
N	226	231

7.4.6. Multivariable logistic regression model

A multivariable logistic regression model was built to estimate the associations of farmer practices and behaviours on belonging to the discordant antimicrobial attitude group. The results are reported in Table 27.

Table 27: Results of multivariable logistic regression for the associations of farmer practices, characteristics and behaviours on farmers belonging to the discordant antimicrobial attitude group compared to the concordant attitude group (N=457)

	N	Odds Ratio (95% CI)	p-value
Using a computer to record information for past three years			
Yes	88	Ref	
No	369	1.996 (1.179, 3.381)	0.010
Did not change worming practices in past three years			
No	120	Ref	
Yes	337	1.879 (1.144, 3.087)	0.013
Used antimicrobials for prevention of disease in all lambs born on farm in previous year			
No	356	Ref	
Yes	101	2.689 (1.571, 4.603)	<0.001
Used antimicrobials for prevention of disease in all ewes in previous year			
No	418	Ref	
Yes	39	3.388 (1.318, 8.706)	0.011
Always trimmed diseased feet in past three years			
No	358	Ref	
Yes	99	2.487 (1.459, 4.238)	0.001
Farmer reported flock made financial loss in past three years			
Yes	54	Ref	
No	403	2.088 (1.079, 4.040)	0.029
My AMU was…			
Less than other farms	239	Ref	
Same as other farms	218	2.495 (1.644, 3.785)	<0.001
Talked to veterinarian about AMU or AMR in past year*			
Yes	267	Ref	
No	190	0.839 (0.550, 1.281)	0.416
Frequency of veterinarian advice*			
Never	30	Ref	
Only once	133	1.016 (0.419, 2.446)	0.972
At least quarterly	294	0.988 (0.422, 2.310)	0.977
Intercept		0.082 (0.033, 0.205)	<0.001

*Variables used interchangeably in model 1 and model 2

The Hosmer-Lemeshow test gave a p-value of 0.5, indicating that the model fit the data well. The mean VIF of the variables used in the logistic regression was 1.07 and the mean tolerance was 0.94 which indicated that there were no collinearity problems.

A second model included the same variables with the same positive or negative associations as the model presented in Table 27. However, "Talked to veterinarian about AMU or AMR" was removed from the model because it was not significant. "Frequency of veterinarian advice" was included to investigate whether this had any association with farmers' attitudes to antimicrobials. Reporting that they received veterinarian advice just once (CI=0.419, 2.446), or at least quarterly (CI=0.422, 2.310) between the period September 2016 and August 2017 had no significant difference in the odds of a farmer belonging to the discordant group, compared to reporting that they did not receive veterinarian advice in that time period.

7.5. Discussion

This study is novel in that it investigated how farmers' past behaviours may be associated with their attitudes towards AMU. The results suggest that farmers fit into two different groups based on their antimicrobial attitudes. The "discordant" group were more likely to have negative views of reducing AMU and positive views of using antimicrobials for prevention, and therefore have attitudes that are discordant with current AMU recommendations. The "concordant" group were more positive about reducing their AMU and had negative views about using antimicrobials for prevention. Belonging to the discordant group was associated with carrying out traditional practices, whereas belonging to the concordant group was associated with carrying out modern practices and recently changing their practices.

The presence of the discordant group may be explained using the theory of cognitive dissonance within the free choice paradigm, where a decision is freely made by an individual (Harmon-Jones and Harmon-Jones, 2002). Once a farmer had chosen to adopt a management practice, such as prophylactic use of antimicrobials in lambs, the alternative is no longer available and they are now committed to the chosen practice (Jermias, 2001). They may reject cognitions that are dissonant with the practice such as "Preventative use of antimicrobials can contribute to AMR in sheep". They may also exaggerate the positives of their chosen practice such as "Use of antimicrobials is beneficial to prevent disease in my flock" and downplay the positives of the alternative practices by agreeing to statements such as "Alternatives to antimicrobials are not practical to implement". This may explain why farmers who used antimicrobials for prevention of disease were more likely to belong to the discordant group. The results show that in 2017 over one-fifth of farmers in this study were still using prophylactic antimicrobials in all lambs as routine. This is despite the many information sources available to farmers

that show that routine prophylactic AMU is rarely appropriate and alternative strategies exists (AHDB, 2015).

Other traditional practices, such as trimming sheep feet and not changing anthelmintic use, were also associated with belonging to the discordant group. Trimming sheep feet to treat and control lameness is an age-old practice that has been passed down through the generations of farmers (Green et al., 2020). However, this is no longer a recommended practice as it has been shown to increase the lameness prevalence in flocks (Kaler and Green, 2009, Winter et al., 2015). Similarly, routine anthelmintic use has been used by farmers for a long time and has become part of their everyday practices (Bellet, 2018). Guidelines on sustainable parasite control avoiding non-targeted routine anthelmintic treatments have been developed and promoted (Abbott et al., 2012), and evidence shows that sustainable parasite management was associated with lower anthelmintic use without a lower productivity or higher worm burden (Learmount et al., 2016). Yet, it is known that farmers may reject this information in favour of their traditional "family farm" identities and perceptions of productivity (Bellet, 2018). Farmers may discard information on recommended practices for parasite or lameness control due to cognitive dissonance, as the information does not align with their traditional practices.

It is likely that many of these traditional practices will have developed into habits over the years. For example, upon the cue of seeing a lame sheep a farmer will be automatically triggered to carry out foot trimming or on the cue of a certain date a farmer will be triggered to treat their sheep with anthelmintic. When a habit is triggered then alternative practices become less cognitively accessible (Gardner and Rebar, 2019). People will be less open to new information and less likely to seek new information regarding the behaviour or alternatives to the behaviour (Jager, 2003). This makes changes to recommendations for a new alternative behaviour less noticeable, such as using injectable antimicrobials to treat lameness, or determining the need to worm lambs using faecal egg counting. Therefore, habitual behaviour is less susceptible to change. This strong habit formation may be why farmers carrying out traditional practices have attitudes related to AMU that are discordant from current AMU recommendations. According to self-perception theory, people who carry out a habitual behaviour use this behaviour to form their attitudes (Bem, 1972). For example, a farmer may think "I have always used antimicrobials in new born lambs and therefore it must be beneficial". The longer a behaviour is repeated, the stronger the habit will be. Rejecting dissonant information is easier than breaking a strong habit and so the traditional practices will persist along with their cognitions (Jager, 2003).

The farmers who did not use a computer to record farm information for the past three years were more likely to belong to the discordant group.

Electronic recording is a relatively modern practice in sheep farming; for example, electronic identification of sheep became mandatory in the EU in 2010 (DEFRA, 2014). Use of electronic recording is more reliable than paper-based recording as it reduces the occurrence of mistakes and can make data entry easier (Menéndez González et al., 2010). However, many farmers in this study did not use a computer to record information. Kaler and Ruston (2019) showed that barriers to technology adoption by sheep farmers included the belief that technology could not replace the skill of a good stockperson and that farmers needed to have a hands-on approach. Similarly, Rose et al. (2018) identified that farmers' value in their experienced based and situated knowledge was one of the most important reasons why they resisted decision support tools. Using electronic decision support tools were also resisted because they were not able to be used in the farmers' usual decision-making settings. Thus, farmers who resist the adoption of technology often have traditional views of good farming stock keeping skills (Butler and Holloway, 2016, Shortall et al., 2018). Farmers may infer their identity as a farmer based on their past behaviours (Bem, 1972). They might inspect their past behaviour and deduce that they are the type of farmer that behaves this way (Lokhorst et al., 2011, van Dijk et al., 2016). Then, this behaviour becomes incorporated into their self-identity.

Farmers who perceived that they did not make a loss from their sheep flock in the past three years were more likely to belong to the discordant group. Although on average sheep and beef farmers typically make smaller profits than other farming businesses, productivity is an important goal of any farm business (DEFRA, 2019a). It is known that productivity is an important symbol of the "good farmer" (Burton et al., 2008). According to Bourdieu's theory of capital, productivity is a sign of a farmer's economic and cultural capital (i.e. material assets, skills) which is incorporated into their identity as a "good farmer" (Bourdieu, 2011). As their previous practices have been perceived as profitable, these are then linked to the good farming ideal. The cognitions relating to the practices involved, such as antimicrobials are beneficial to productivity, may be reinforced because of the positive outcome.

Farmers who believed that their AMU was the same as other farms were more likely to belong to the discordant group. Therefore, farmers in the discordant group may think that the way they perceive AMU is similar to other farmers (i.e. a descriptive norm). This is similar to findings in a study of dairy farmers, where perceived norms around mastitis treatment hindered appropriate AMU (Swinkels et al., 2015). Farmers may also perceive that using antimicrobials is part of the injunctive norm of being a "good farmer" as they believe antimicrobials improve productivity and prevent disease. It is difficult to change behaviour or attitudes if farmers believe they would violate the norms around AMU. However, this study suggests that beliefs that are discordant with current AMU recommendations are not actually the norm

amongst sheep farmers. Many farmers belonged to the concordant group whose beliefs aligned with current AMU recommendations. This could help to dismantle the perceived norms within the discordant group (Ritter et al., 2017).

The frequency of veterinarian advice and whether the farmer reported that they had specifically spoken with their veterinarian about AMU were not significantly associated with farmers' antimicrobial attitude group. This may be because veterinarians were not obviously speaking with farmers about appropriate AMU at the time of the study. Studies from pig, poultry, and dairy sectors found that veterinarians were a key source of information on AMU for farmers (Jones et al., 2015, Etienne et al., 2017, McDougall et al., 2017). Some farmers may find their veterinarian's advice confusing or that it conflicts with other advice (Doidge et al., 2020c). Additionally, some sheep veterinarians may think that it is still acceptable to prescribe routine antimicrobials for the prevention of neonatal lamb disease and this view could then be disseminated to their clients (Doidge et al., 2019). One method of reducing dissonance is through socialising with those that hold cognitions similar to those one wishes to maintain (Festinger, 1957). Therefore, farmers may choose to use a veterinarian based on their views on antimicrobials. On the other hand, some farmers may ignore their veterinarian's advice if it does not align with their practices. It has been shown that some farmers do not take their veterinarians advice around prophylactic AMU in lambs (Doidge et al., 2020a). Farmers may not listen to their veterinarian's advice because of their resistance to change their practices. They ignore feedback that disagrees with their chosen behaviour. As questions on quality of veterinary advice were not included in the survey, we cannot determine the quality of advice the farmers in this study received from their veterinarians. It is plausible that it may be the quality rather than the quantity of veterinary contact that may help to change farmers' opinions on antimicrobials. Further research is required to understand how we can change the behaviour of those that carry out traditional or habitual farming practices that are no longer recommended.

7.5.1. Limitations

The median number of ewes was larger in the survey population than the national average (DEFRA, 2019b) and may not be representative of the British sheep industry as a whole. However, the sample is likely to be representative of sheep farmers who supply lamb deadweight and who are aligned to a retailer. This was a general flock health survey that was not specifically based on AMU. Responses therefore should not be biased towards those with a particular interest in AMU. There may still be some selection bias as there may be differences in the farmers who participated in the study compared with those who did not participate in the study. As practices were self-reported by the farmers, there may be a risk of recall bias. Recall was enhanced in this study by including pictures of different types of

antimicrobials to aid memory and including indication oriented and drug oriented questions (Gama et al., 2009). Additionally, the survey encouraged respondents to refer back to their medicine books rather than relying on memory. Social desirability bias may occur where respondents give responses that they believe are more socially acceptable, rather than reporting their true beliefs or practices (De Vaus, 2013). This might arise around AMU, which could be considered a sensitive topic. However, given that many respondents in this study did not provide socially acceptable answers (e.g. over a fifth using antimicrobials in all lambs for prevention of disease), this may not be the case. Finally, this study used a cross-sectional design, to investigate the influence of behaviours on attitudes. Therefore, this study only measures the associations between behaviours and attitudes and does not infer causality. A longitudinal intervention study is required to further strengthen the evidence that past behaviours can influence farmers' attitudes towards antimicrobials and understand whether there is a causal link.

7.5.2. Implications for antimicrobial behaviour change

One potential way of achieving recommended behaviours is through sharing positive attitudes towards antimicrobial stewardship (De Vos and Singleton, 2020). For those that are already using antimicrobials appropriately, sharing positive attitudes towards antimicrobial stewardship will increase and reinforce the consonance between their behaviour and attitudes and the behaviour will remain constant. For farmers who are using antimicrobials for prevention of disease, an improved attitude towards antimicrobial stewardship may increase the disagreement between the behaviour and attitudes (Festinger, 1957). This may lead to a reduction in prophylactic AMU. The main differences in attitudes between the concordant group and the discordant group were that the discordant group believed that antimicrobials were beneficial for productivity and prevention of disease in their flock, that reducing AMU would have costs, and that alternatives were not practical to implement. This shows a bias towards a salient choice to use antimicrobials to prevent diseases in their flock, as well as bias towards cost/time saving.

If behaviours are carried out due to habit, then information campaigns will not work as the information will not be received by those who it is aimed at (Whitmarsh et al., 2012, van Rijn et al., 2019). Instead, interventions that change behaviour through disrupting the contextual cues to enact a behaviour could be used (Kurz et al., 2015, Gardner et al., 2019). Alternative strategies used to prevent disease in sheep need to become the salient choice in this context. This means alternatives should be convenient and available to the farmer compared with antimicrobials, which should be less prominent and less readily available. To break contextual cue-behaviour associations, it may be useful to plan ahead by preparing responses to anticipated AMU cues (Kurz et al., 2015). This could be incorporated into the annual flock health

plans that farmers are required to complete as part of farm assurance schemes (Red Tractor Assurance, 2018).

Behaviours could also be changed by targeting farmers' self-identity. Farmers may infer their self-identity as a traditional or good farmer from their past behaviour (Bem, 1972). When a recommended behaviour is identity-incongruent, then farmers may believe that behaviour is "not for people like me" and will not carry out the behaviour (Oyserman and Destin, 2010). Thus, recommended practices need to be shown to link with identities of a productive, profitable farmer. Further research is required to understand the broad practices involved with shaping a farmers identity to inform identity-based interventions.

Finally, practices not directly related to AMU were associated with farmers' antimicrobial attitudes. There may be a dynamic interdependency between farming practices (Hidano et al., 2018), and it may be possible to change AMU behaviours through targeting other behaviours such as lameness control, anthelmintic control or computer recording. This is called behavioural spillover (Jones et al., 2019). Therefore, interventions may be measured by their effectiveness for multiple behaviours, rather than just a single direct behaviour.

7.6. Conclusion

Overall, farmers who had antimicrobial attitudes that were discordant with current AMU recommendations carried out traditional practices, which was strengthened by their positive perceptions of their profitability. This may be explained by cognitive dissonance theory and self-perception theory where farmers matched their attitudes to the behaviours they carried out. Additionally, habit may play an important role in farmers having attitudes that did not align with optimal AMU recommendations; whereas veterinary contact did not influence farmers' attitudes towards antimicrobials. These results suggest that potential behaviour change interventions focussed on refining AMU should challenge habitual behaviours through targeting farmers' self-identity, disrupting the contextual cues of AMU, and improving positive attitudes towards antimicrobial stewardship.

8. Study 6: Understanding farmers' decision-making around prophylactic AMU in lambs: Qualitative analysis and natural language processing of online discussion forums

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Author contributions:

CD and JK conceptualised the study and had roles in the methodology. CD had roles in data curation, formal analysis, investigation, project administration, visualisation and writing (original draft). EF contributed to concepts of luck and fate. JK supervised the analysis and FL contributed to critical discussions. JK acquired funding for the project. All authors contributed to reviewing and editing.

8.1. Abstract

The routine use of antimicrobials for prevention of disease in neonatal lambs has been highlighted as inappropriate, yet research suggests that many farmers in the UK still carry out this practice. The aim of the study was to understand farmers' naturalistic decision-making around prophylactic AMU in lambs. Data from 431 posts by 133 different users of an online discussion forum were analysed quantitatively using natural language processing and qualitatively using a grounded theory approach. Results from the qualitative analysis identified five categories that influenced farmers risk perceptions around prophylactic AMU in lambs: anticipated regret, negative emotions and experiential avoidance; economic considerations; farmer identity; perception of capability; and perception of social judgement. Natural language processing analysis of the posts by the study group were compared to posts on topics unrelated to AMU by control groups from the same forum to understand the underlying style and tone within the text. Analytical thinking and authenticity scores were significantly lower in the study group compared to the control groups ($p<0.01$). Words relating to cognitive processes were significantly higher in the study group compared to the control groups ($p<0.01$). Results of the qualitative and quantitative analysis were integrated to assess the fit of the data and enhance findings from either method alone. The key findings were the identification of reasons why farmers used

antimicrobials prophylactically in neonatal lambs. Farmers disassociated the use of oral antimicrobials in neonatal lambs from other types of antimicrobials within sheep farming. Farmers used the concept of luck and uniqueness to justify their prophylactic AMU. This may explain farmers' low analytical thinking scores as this reflects a more personal style of thinking as farmers express their thoughts on AMU on an individual basis. Farmers' felt that they did not have the capabilities to control neonatal disease without antimicrobials during busy periods and this was exacerbated by external economic constraints. For farmers' who used antimicrobials for therapeutic use, fear of social judgement was an important factor in their perceptions of risk around AMU. The high frequency of negations and conjunctions suggested feelings of moral duty. As such, AMU has developed into a symbol of their good farming identity which conflicted with the identity held by those who used antimicrobials prophylactically. These results can be used to inform knowledge exchange around prophylactic AMU in lambs to improve antimicrobial stewardship in the sheep farming sector.

8.2. Introduction

The sheep industry is the largest livestock sector in the UK in terms of biomass (VMD, 2018), which makes it particularly important that any routine prophylactic AMU is carefully scrutinised. Although relatively little details are known about the precise quantities of antimicrobials used on sheep farms, available data suggests low levels of total antimicrobials are used in the sheep industry in comparison to in the other livestock sectors (VMD, 2020b).

Antimicrobials are used in the sheep sector commonly for the treatment or prevention of diseases of neonatal lambs such as colibacillosis (watery mouth) and septic polyarthritis (joint ill) (RUMA, 2020). Previous reports suggest that as many as 31-68% of UK sheep farms use antimicrobials prophylactically in neonatal lambs (Douglas and Sargison, 2018, Lima et al., 2019).

Given the large proportion of farms in the UK using antimicrobials prophylactically in neonatal lambs, this is an area that calls for stewardship and more responsible use of antimicrobials. There are many resources available for farmers that focus on why the prophylactic use of antimicrobials for neonatal diseases is in many cases unnecessary (AHDB, 2015, RUMA, 2019a). Current "good practice" for prevention of neonatal disease includes providing sufficient colostrum to new born lambs through appropriate ewe nutrition (RUMA, 2019a). Additionally, farmers should practice good hygiene, which includes regular hand washing and disposable gloves. If lambing indoors, navels should be treated, pens should be freshly bedded with clean straw and dry disinfectant or lime should be spread before re-bedding pens between ewes (AHDB, 2015). Antimicrobials should only be used in the signs of illness. Yet, many farmers continue to administer antimicrobials prophylactically to neonatal lambs (Study 5) (Lima et al., 2019). Research is

required to understand sheep farmers' decision-making around this behaviour.

Most research on farmers' decision-making around AMU have used observational research techniques such as interviews (Poizat et al., 2017, Golding et al., 2019, Doidge et al., 2020c), focus groups (Coyne et al., 2014) or surveys (Brunton et al., 2012, Jones et al., 2015). AMU in agriculture could be considered a sensitive topic due to the public and media attention it receives, which may make it difficult to study farmers' true opinions on this issue. Farmers may be aware that using antimicrobials for prevention is not considered "good practice" and this could result in social-desirability bias when faced with observational research techniques. Additionally, selection bias may be present, where farmers who are interested in AMU are more likely to take part. It may be difficult to contact farmers who carry out undesirable behaviours and they may not be willing to take part in research and talk about their motivations or experiences (Elliott et al., 2005).

As discussed in Section 2.3.5, internet use in GB is widespread and provides a wealth of online data (Office for National Statistics, 2019). To reduce issues with bias surrounding sensitive topics, online data from discussion forums has been used to investigate research topics such as male infertility (Hanna and Gough, 2016), drug use (Davey et al., 2012) and depression (Moore et al., 2016). Whilst in human medicine analysis of online discussion forums have been used to understand patients' decisions around AMU (Santer et al., 2017, Ghouri et al., 2019), there has been no such investigations in veterinary medicine to investigate farmers decisions.

Online forums allow natural conversations to be observed without the involvement of a researcher. Thus, farmers may be able to express their opinion freely without any perceived judgement. Online discussion forums often form communities where users can share ideas, ask for advice and seek social support (Gill and Whisnant, 2012). This allows researchers to study the deeper motives, attitudes and experiences of a group of farmers who may not normally take part in observational research.

Whilst qualitative analysis can identify the textual meanings of online posts, quantitative analysis can be used to describe the content in a systematic manner by identifying general trends in behaviour, motivations or emotion. Natural language processing can be used to quantify the frequency of word categories within pieces of text. Researchers can make inferences from the frequencies of word categories, many of which have been shown to be correlated with different psychological processes (Tausczik and Pennebaker, 2010).

Combining both qualitative and quantitative data analysis (known as data analysis triangulation) enhances the trustworthiness of the results (Renz et

al., 2018). Furthermore, data analysis triangulation can reveal findings that would not be shown using either method alone. Triangulation therefore strengthens the ability to interpret results and provides multiple perspectives of the topic being investigated (Renz et al., 2018).

The aim of this study was to use a combination of grounded theory and natural language processing to analyse internet forum posts to understand how farmers make decisions around using, or not using, prophylactic antimicrobials in neonatal lambs.

8.3. Methods

8.3.1. Study sample and data collection

One large UK based forum specifically related to agriculture was selected for this research. The forum was accessible to be read by non-members, but only members could create threads or reply to other users' posts. The forum was searched for the terms "watery mouth", "joint ill" and the name of an oral product that contains spectinomycin. This antimicrobial product (active ingredient spectinomycin) was chosen as a search term as it is the most commonly used oral antimicrobial for watery mouth. It is authorised for use in lambs and piglets in the UK, though the majority of search results were related to its use in lambs. Threads identified were reviewed to determine those with relevant discussion of AMU in neonatal lambs. The researcher remained a guest on the forum and did not register as a user, post on the forum or declare presence of a researcher to ensure data collection was unobtrusive.

Posts from threads based on weather and grassland management were also collected from the same forum. The grassland management and weather posts were used as control groups as they were unrelated to AMU. These controls were chosen as they were both topics that sheep farmers have experience in and are likely to engage in. They offer two different types of discourse to compare with the AMU threads. Previous research suggests that weather may have effects on farmers' mental health (Daghagh Yazd et al., 2019); therefore, it was anticipated that discussion of the weather may have low emotional tone. Whereas, grassland management may require users to think analytically (Gibon, 2005). The control posts were gathered until the number of users were similar to that gathered for the study group.

8.3.2. Ethical considerations

This analysis follows the guidelines set out by the British Psychological Society on internet mediated research (British Psychological Society, 2017). The forums accessed for analysis did not require registration to view forum posts and were therefore located within the public domain. Forum users were instructed not to post any private or confidential information upon registering an account. As the posts were publicly available and did not contain private

information, no steps to gain informed consent from those posting were taken. To ensure anonymity of forum users, any identifiable information about participants and forum sites was removed to maintain confidentiality (Tilley and Woodthorpe, 2011). In addition, to preserve anonymity quotes have been paraphrased and researchers took steps in terms of checking all quotes using a search engine to ensure they cannot be traced (Roberts, 2015). The study was approved by the University of Nottingham School of Veterinary Medicine and Science Ethics Committee (no. 3232 200915) (Appendix 10).

8.3.3. Qualitative data analysis: grounded theory

A grounded theory approach was used for data collection and analysis (Glaser and Strauss, 1967). Forum threads were selected using the purposive theoretical sampling method, where new threads were identified throughout the data collection process. Ten threads were selected for analysis which included multiple threads on watery mouth prevention, joint ill and one thread on general lambing time for 2019. There were 431 posts from 133 different forum users. The forum posts dated from 2015 to 2019 and were accessed October 2019. The relevant threads and posts were copied onto a Microsoft Word document and uploaded into NVivo (NVivo qualitative data analysis Software; QSR International Pty Ltd. Version 12, 2018) to support analysis. Data were coded using the constant comparative method (Maykut and Morehouse, 1994). First, initial coding was carried out where each discussion thread was read multiple times and relevant posts coded line by line. Then, focussed coding was carried out where clusters of data that were relevant to a particular interpretation were grouped together. Connections were made between codes to produce categories. Categories were reviewed and refined after analysis of each discussion thread until data saturation was achieved. The final categories were defined and related to each other to establish a theoretical concept (Charmaz, 2006). An explanatory theory for farmers' decision-making around prophylactic AMU in lambs was produced.

8.3.4. Quantitative data analysis: natural language processing content analysis

The programme Linguistic Inquiry and Word Count (LIWC) was used for the content analysis of the forum posts (Pennebaker et al., 2015a). LIWC analyses text by reading each target word and classifying it into various categories. The categories include general descriptor categories, linguistic dimensions (e.g. pronoun use) and psychological constructs (e.g. cognitive, social, and affective). The programme quantifies the relative frequency of words that belong to each category. There are also four summary variables that are based on a 0 to 100 scale using percentiles derived from large comparison samples (Pennebaker et al., 2015b). These variables are clout, analytical thinking, authenticity and emotional tone. An explanation of the LIWC variables used in this study are presented in Table 28.

Table 28: LIWC variables used to address the research question (Adapted from Pennebaker et al. (2015b))

Variable	Explanation
Clout	Scored from 0 to 100 using percentiles. A high score reflects a more confident style, whereas a low score reflects a more tentative style.
Analytical thinking	Scored from 0 to 100 using percentiles. A high score reflects a more formal way of thinking and a low score reflects a personal, narrative style of thinking.
Authenticity	Scored from 0 to 100 using percentiles. A high score indicates an honest, personal style, whereas a low score indicates a guarded, distanced style.
Emotional tone	Scored from 0 to 100 using percentiles. This variable reflects the difference between the use of positive and negative emotion words. A high score indicates a positive tone and low score indicates a negative tone. Scores below 50 are suggestive of negative emotional tone.
Function words	Count of function words posted by a forum user e.g. it, to, not, very.
Conjunctions	Count of conjunctions posted by a forum user e.g. and, but, whereas.
Negations	Count of negations posted by a forum user e.g. no, not, never.
Cognitive processes	Count of cognitive process words posted by a forum user e.g. cause, know, ought.
Social processes	Count of social process words posted by a forum user e.g. mate, talk, they, child.
Risk words	Count of risk words posted by a forum user e.g. danger, doubt.
Money words	Count of money words posted by a forum user e.g. audit, cash, owe.

LIWC has been validated for numerous psychological domains (Tausczik and Pennebaker, 2010). Many psychological processes can be reflected in the way words are used. Function words (e.g. pronouns, conjunctions) have been shown to be more useful gauges for psychological processes than content words (e.g. verbs, adjectives and adverbs) (Pennebaker and Chung, 2013). For example, an increased use of function words was associated with negative events compared to positive events (Barnard et al., 2020).

The forum posts for each forum user were entered into an Excel spreadsheet where each user was a single row. The spreadsheet was imported into LIWC for analysis of the text. A group of forums posts based on the weather were included as a control group (n users weather=140). A further control group of posts based on grassland management was included (n users grassland=128). Users with <20 words were removed from the analysis (n(study)=22, n(weather)=47, n(grassland)=20). As the data were not normally distributed, the variable distributions for the study group were compared with the weather and grassland group using a Kruskal-Wallis test in Stata 16 (Stata SE/16.1, Stata Corp., College Station, TX, USA). Dunn's Test was used as a

post-hoc test to identify differences between the three groups and p-value of <=0.05 was considered significant. A Benjamini-Hochberg adjustment procedure was used to avoid type I errors (Benjamini and Hochberg, 1995).

8.3.5. Integration of qualitative and quantitative results

For the assessment of the fit of the data, quantitative and qualitative results were presented in a table with the potential outcomes of convergence, complementarity, expansion, and divergence (Morgan, 2019).

8.4. Results

8.4.1. Qualitative analysis

Most threads were started by a farmer asking for advice as they had a problem with neonatal lamb disease, either watery mouth or joint ill. Other farmers were able to relate to the issue, having experienced something similar themselves and would give advice on what they would do in that situation. Often farmers would give opposing views on the matter, which resulted in debate over using antimicrobials for prevention. The views for and against the prophylactic use of antimicrobials given by the farmers showed that there were two opposing risks that they considered: (1) the risk of only using antimicrobials for treatment in lambs and (2) the risk of using prophylactic antimicrobials in lambs. The five major categories identified and their corresponding subcategories are presented in Table 29.

Table 29: The categories and sub-categories relating to farmers' decision-making around AMU in neonatal lambs identified from the qualitative analysis

Major category	Subcategory
Perception of social judgement	Influence of laws and restrictions Influence of consumers and animal rights
Economic considerations	-
Good farming identity	A good farmer doesn't need to rely on antimicrobials Animal welfare is the priority
Perception of capability	Positive perceptions of capability Luck, fate and chance External factors restrict farmers' capabilities
Anticipated regret, negative emotions and experiential avoidance	-

8.4.1.1. Perception of social judgement

8.4.1.1.1. Influence of laws and restrictions

Many farmers raised concerns for the future if the prophylactic use of antimicrobials carried on. Some farmers were worried that antimicrobials would become restricted in the future if they were not seen to act responsibly. Farmers were afraid of this happening in the UK as it could result in poor welfare and farms shutting down. Others have stopped using antimicrobials prophylactically as they were aware of the risks of not having access to antimicrobials in the future:

"Routine, prophylactic AMU is under pressure from governments and the EU. This will not be imposed by our vets but from above. For example, in the Netherlands vaccines have moved from general use to prescription only and so have to be administered by a vet."

Farmers also mentioned that their veterinarians were encouraging them to reduce their prophylactic AMU. Those that took their veterinarians advice managed to successfully get through a lambing period without any problems.

"My vet has been warning about restrictions to antimicrobial for a while."

"I lambed without antimicrobials last year mainly because our vets told us to only use it if you get an issue."

However, there were a group of farmers who did not feel compelled to follow their veterinarians' advice. These farmers were more resistant to the social pressures around using antimicrobial responsibly.

"My vet who does not agree with routine use of antimicrobials allows me this small concession to his standard lecturing."

"My vets don't bother to give me the usual addressing on AMR when I ask for it."

8.4.1.1.2. Influence of consumers and animal-rights

Some farmers appeared uneasy about others in the forum expressing a reliance on antimicrobials for neonatal disease, for fear of what consumers may think. They thought that consumers would not buy lamb meat if they knew prophylactic AMU in lambs was a common practice.

"How do you think that sounds to consumers? Don't forget you need them to buy your product."

"The industry needs to be seen to cut down AMU."

Additionally, they were concerned that animal-rights activists could potentially use this information, which could be damaging to the sheep farming image of grass-fed, extensively reared lamb.

"The thought of eating early born lamb that has only survived its short life with overuse of antimicrobials really puts me off lamb. I am sure most consumers think of lamb as being natural born and reared on grass. You are playing right into the animal rights activists' hands."

As well as the social responsibility for appropriate AMU, there appeared to be a moral responsibility where prophylactic AMU was not seen as "doing the right thing". They believe that only using antimicrobials responsibly in the sheep industry would be a good thing to do in the eyes of society

"Used to give everything an antimicrobial pill, but stopped that years ago now as it didn't seem right doing it to everything."

"Routine use of antimicrobials in lambs or ewes is not something that sits well with me."

In summary, this category highlights the concerns farmers have around the potential restrictions on AMU in the future and how they felt a moral obligation for antimicrobial stewardship. Farmers were worried about the impact on their image if consumers or animal rights activists were aware of others using antimicrobials as a prophylactic. Farmers who use antimicrobials as routine in their lambs appear resistant to the social pressures around antimicrobial stewardship and were unwilling to adhere to their veterinarians' advice.

8.4.1.2. Economic considerations around AMU in lambs

Economic considerations were an important factor in the decision *not* to use prophylactic antimicrobials. Some farmers were concerned about the financial consequences of AMR in the long term if sheep farmers carried on routine treatment of lambs with antimicrobials. A few farmers related this risk to their experiences of anthelmintic resistance, which has become a widespread problem for sheep farmers:

"Anyone who has experienced resistant fluke will tell you it is nothing to look forward to."

They also considered the financial implications of AMR due to untreatable infections or reliance on expensive antimicrobials. They were concerned that other farmers were not thinking about the future:

"There has to be a balance, use cheap antimicrobials now and make money until you get AMR and the antimicrobials no longer work. Then pay through the nose for more expensive new drugs or have to do without all together?"

Economic considerations were often an important factor in the decision to use antimicrobials prophylactically. It was seen as cheaper to use antimicrobials than to lose a lamb to neonatal disease. Spectinomycin was seen as a particularly cheap antimicrobial that was worth giving to all lambs "just in case" they needed it. It was considered much cheaper than the cost of other practices that prevent neonatal lamb diseases, such as lime or straw.

"If I waited until I lost a lamb to watery mouth I would be down [£X] minimum plus the bottle of antimicrobials I would waste because nothing dies uncared for on my farm, versus the [£X] it costs to treat all my lambs."

"I give antimicrobials to every lamb without fail. It is cheap and effective."

Occasionally, because farmers could not afford to employ more staff around lambing, there were not enough members of staff to attend to lambs thoroughly, so antimicrobials were used to reduce perceived risk. Some believed that if prophylactic antimicrobials were not used, shepherding costs would increase so much that farming would not be viable.

"When you're on your own lambing sheep because of the financial side of the job, the weather is bad, you're tired and there aren't enough hours in the day it's quite different!"

Overall, this category identifies that the economics of AMU were considered both in the long-term and in the short-term. In the long-term, farmers were concerned about the increased costs due to AMR, whereas in the short-term farmers were concerned about covering lamb losses and keeping their business afloat.

8.4.1.3. Good farming identity

This category centres on the perception of a conflict between two good farming identities. It highlights the importance of animal welfare in being a good farmer for both identities, but also the relative importance of low AMU. Hence, there are two sub-categories: "A good farmer doesn't need to rely on antimicrobials" and "Animal welfare is the priority".

8.4.1.3.1. A good farmer doesn't need to rely on antimicrobials

With every post that suggested using antimicrobials for the prevention of neonatal disease in lambs, there were farmers that argued against this practice. Being able to maintain good animal welfare whilst using antimicrobials only when necessary were seen as traits of a good farmer. By contrast, it appeared those that were relying on prophylactic AMU were seen to be compensating for suboptimal management practices. In response to others saying that methods to control neonatal disease were not practical, some farmers provided their own account of how they manage without antimicrobials:

"We used to use spectinomycin but now we now focus on bedding, making sure lambs are dry and not in draughts, and feeding ewes to ensure colostrum is good. We are getting on better so far with better husbandry."

They also challenged other farmers' excuses for their reliance on antimicrobials:

"We have straw sheds and lamb early and always have time to clean the pens."

Some farmers suggested changing routine management practices to prevent diseases in the first place. For example, a few users wrote about their experience of stopping tail docking and castration in which it reduced the number of lambs with joint ill. Ceasing this routine practice came as a shock to some of the other farmers suggesting that this would cause other welfare problems. Others began to contemplate whether the tail docking and ring castration they carried out was necessary. This suggested that the set of experience-based rules relating to tail docking in farming practice was gradually shifting.

> *"When we lamb outside we get no joint ill, especially if you don't ring. Is it something that still needs doing or will the time come when no one does it?"*

8.4.1.3.2. Animal welfare is the priority

However, low AMU was not the only good farming identity sub-category. Some argued that using antimicrobials was better for the welfare of the animal – that prevention was better than cure. Having healthy lambs was important to them and they believed that this was what made them a good farmer:

> *"It all comes down to the issue of welfare. Is it right not to use spectinomycin and then the lambs get joint ill and have welfare issues, or is it better to prevent these welfare issues?"*

> *"The public would be more disgusted to see images of tapeworms and fluke in offal, images of parasites in meat and images of starving lambs with watery mouth."*

There were high emotions when farmers' who were using antimicrobial prophylactically were confronted with other farmers suggesting that many cases of watery mouth or joint ill were caused by unhygienic conditions. Farmers would become defensive, as they felt insulted that other farmers were implying that their farm or sheep were dirty. This shows a conflict in good farming identities:

> *"The dirty comments from some of the [x] are a bit condescending. There are farms sparing on straw but there are many that always have sheds with fresh straw and still get problems."*

> *"Wow, my sheep aren't dirty."*

When one user asked how others used antimicrobials over the lambing period there appeared to be a separation of spectinomycin – an oral antimicrobial commonly used for treatment or prevention of watery mouth – from other types of antimicrobials. It seemed as if the prophylactic use of spectinomycin was more acceptable than using other antimicrobials that were injectable. Spectinomycin was used more liberally than parenteral (injectable)

antimicrobials. The use of spectinomycin had become a cultural norm and was part of the rules of the game that define their good farming identity. Thus, spectinomycin use did not harm their good farming identity but use of parenteral antimicrobials could.

> *"Do you mean to take account of spectinomycin? We use spectinomycin in all lambs but other antimicrobials are only used when needed."*

> *"We only use spectinomycin regularly but always have [parenteral antimicrobial] nearby. Some family members routinely inject lambs."*

This category therefore illustrates the presence of two good farming symbols – one of good animal welfare and one of low AMU. The two symbols can conflict with each other and some farmers do not recognise responsible AMU as a good farming symbol. The routine prophylactic use of spectinomycin appears to have become a cultural norm in sheep farming.

8.4.1.4. Perception of capability

8.4.1.4.1. Positive perceptions of capability

Farmers agreed that good hygiene and colostrum intake by lambs was the best way to prevent neonatal disease in lambs.

> *"A clean environment and plenty of good colostrum is the basic first defence."*

> *"Plenty of colostrum trumps all. How many single lambs do you see go down with watery mouth? Not many."*

Farmers who did not use antimicrobials prophylactically wrote about the practices that they implemented to prevent neonatal disease. They believed that farmers did not need to rely on antimicrobials to prevent disease and urged other farmers to change their practices if they did so.

> *"You need to change your system. We manage to clean out every [X] hours or between every other ewe... For an area of [X] ewes, I like to use a round bale of straw every other day. It might be excessive but our joint ill and scouring is under [X]%."*

Farmers occasionally wrote about how they weaned themselves off using prophylactic antimicrobials. These were farmers who had previously used antimicrobials in all lambs and over the years reduced the numbers of lambs treated with antimicrobials. Over time they have realised that they did not need to use antimicrobials routinely and they are capable of preventing neonatal lamb disease without a reliance on antimicrobials.

> *"I lamb indoors and used to use antimicrobials on multiples starting part way through lambing. This year I have only dosed the triplets and*

only because I had some left in the fridge. Next year I will not use it unless there is a problem."

"We used to give antimicrobials to all the multiples as we used to see a lot of watery mouth in our old barns and the practice continued when we got new barns. I decided to only use spectinomycin on weak lambs. It was effective as we did not get any cases and we did not use antimicrobials routinely."

8.4.1.4.2. Luck, fate and chance

In some cases, farmers were frustrated as they felt they were following best practice and still ended up with ill lambs. They did not know how other farms could manage without having to use antimicrobials around lambing time. In the cases where farmers seemed to be following good practice, getting incidents of neonatal lamb disease appeared to be attributed to chance. Often, farmers said that some farms can "get away" with not using antimicrobials, suggesting these farmers do not experience the disease because they have been lucky.

It is useful at this point to distinguish between luck, fate and chance (Ferguson and Cox, 1996). Fate refers to a sense that an event is predetermined, whereas chance is the probability of an event happening and is linked to uncertainty. Luck is somewhat more complex and relates to something that may be seen as a property of the person (an internal factor) or the context (it was luck that x happened), but luck can be balanced: I am a lucky/unlucky person, others are more or less lucky/unlucky compared to me or that was a lucky/unlucky event.

The quote below relates to some farmers being luckier than others. Success is determined by who you are.

"Some farmers may need antimicrobials more than others, whereas others would get away with it. Sufficient colostrum has more to do with it than clean pens; you can be cleaning pens out after every ewe and still get it."

Some farmers indicated than even with good management practices lambs can become ill and so use of antimicrobials becomes the only option and is linked to the idea of chance and fate.

"Whatever system we use, whether we lamb outside, dip their navels, use antimicrobials; I don't think we can ever be freed of this threat."

"I agree about trying to keep sheds dry and clean, but this disease will cause problems in flocks with good hygiene too."

There was often the view that farms are not all the same and a practice that works for one farm may not work for another. There was a perception of

'uniqueness' on every farm and farms could not be compared. Farmers needed to consider the area of their farm and season of lambing when controlling neonatal lamb diseases; again reflecting uncontrollable factors linked to fate or chance.

> *"You don't have to do anything wrong. One of my vets told me it depended what area you were in to a degree. With having sheep in different locations I could agree."*

> *"There is a lot of difference in the day lengths and dampness between December and March so you are not comparing like for like."*

Whilst most farmers appeared to be aware of the risks of AMR through using antimicrobials for prevention, many argued that the control measures such as cleaning out pens and putting down lime were not practical to implement. Again, this relates to uncontrollable events like the weather and again chance.

> *"In reality, when the weather is bad so you can't turn the ewes out and it's in the early hours of the morning and you're tired no one is going to be cleaning out pens."*

This argument for using prophylactic antimicrobials over implementing control measures was particularly prevalent later in the lambing seasons, once fatigue had begun to set in:

> *"At this time of year we get more cases because E. coli is building up in the sheep and fatigue is taking its toll. We are not as observant in seeing triplets suck properly. From now on all triplets will get a shot of spectinomycin."*

8.4.1.4.3. External factors restrict farmers capabilities

There were times where farmers wanted to use best practice but were restricted by external factors. Farmers suggested that starting the lambing season later (around April or May) provides a better environment for reducing disease burden due to more favourable weather. However, for a few farmers, the market demand meant that they have shifted their lambing time to "higher risk" periods of December and January when the weather is generally colder and wetter. This means ewes and lambs were more likely to be housed indoors, making it easier to transmit disease.

> *"We lamb early because our contract tell us when lambs are required for the supermarket. We are producing for public demand rather than for the sake of it."*

The low profit margins for sheep meant that farmers were rearing larger flocks without an increase in employment which puts strain on their capability to manage hygiene with sheds at busy periods.

"I can see why those lambing a lot of sheep see spectinomycin as sensible insurance."

For those that were still farming on a small scale, every lamb loss had a massive impact on productivity.

"I would ask whether [X] ewes would ever be worth the energy"

"I only have a handful of lambs born compared to many farms, so one ill lamb is too much."

Market demand also meant that some management practices that could potentially reduce disease were not taken up. For example, one farmer stated that although castrating lambs may result in more joint ill cases, they need to castrate ram lambs otherwise their abattoir would not take them.

"The testicles – many abattoirs don't want to see them unless we nip them at weaning which leads to extra stress on the animals."

Additionally, some farmers with joint ill problems were aware of a vaccine for a particular causative agent, *Erysipelothrix rhusiopathiae,* which was available for pigs. However, because it is not licenced for use in sheep in the UK, they were refused prescription by their veterinarian. *Erysipelothrix rhusiopathiae* is not the most common cause of joint ill in lambs in the UK, but is most commonly associated in older lambs, with outbreak situations and after tail docking or castration (Lloyd et al., 2016, Opriessnig et al., 2020).

"What are the legalities of the Erysipelothrix vaccine? My vet won't let me have it but he lets me have other drugs off label. Why is the vaccine different?"

Overall, this category highlights that there are many farmers who believe they are capable of preventing neonatal disease through maintaining hygiene and optimal colostrum quality without routine prophylactic use of antimicrobials. It also highlights that there are many barriers towards perceiving this capability. Farmers believed that neonatal disease is partly down to luck, fate or chance that they had no control over the disease, and that at the peak of lambing they were too tired or did not have enough time to carry out the desired management practices. External factors such as market demand and veterinarian restrictions exacerbated this perception of lack of capability which influences the routine use of antimicrobials in neonatal lambs.

8.4.1.5. Anticipated regret, negative emotions and experiential avoidance

This final category centres on the negative emotions experienced at lambing time. These emotions are linked to the concept of anticipated regret, that the farmer knows they will regret it in the future if they do not act now.

The emotional strain of having animals die from diseases that are seen as preventable affected farmers decision to treat lambs with antimicrobials. Sometimes they have tried to avoid routinely using antimicrobials prophylactically at lambing time in the past but due to bad experiences have resorted back to this use. The use of routine prophylactic antimicrobials was an act of experiential avoidance - an attempt to avoid uncomfortable thoughts, feelings, experiences or memories (Hayes et al., 1996). They learn to cope with the bad experience by controlling or avoiding it through routine prophylactic AMU.

> *"The allow your flock to evolve [without antimicrobials] argument almost broke me – both financially and mentally – when it killed [x] percent of my lambs in 48 hours a few years back. Best practice is an aspiration but surviving is a necessity."*

There was even a case when an outbreak not related to bacterial diseases, nematode infection, spurred the use of blanket prophylactic AMU in lambs. The farmer wanted to ensure lambs were not dying from preventable disease because of the negative emotions they had previously felt.

> *"We had something similar with nematodirus a few years ago, never again do I want to feel like that so we do the same [give spectinomycin to all lambs]."*

Occasionally, farmers said that the use of antimicrobials was a matter of life or death. To them, lambs becoming ill was inevitable if they did not routinely use antimicrobials prophylactically. They were confident that prophylactic antimicrobials played an important role in their disease prevention and anticipated that they would get neonatal disease if they did not use antimicrobials.

> *"If early lambing flocks can't use spectinomycin then it will mean increased use of other drugs to treat lambs once they become infected."*

Thus, antimicrobials were used in an attempt to minimise contact with unpleasant experiences and provide instantaneous relief. Often, the immediate effects of experiential avoidance are positive (Hayes et al., 1996). Indeed, the lack of lamb deaths or cases of neonatal disease after the routine use of prophylactic antimicrobials provided a short-term positive effect and reinforcement for the behaviour, even though doing so may create harm in the long run (Hayes et al., 1996). The below quote also shows that farmers had misconceptions about the effectiveness of oral antimicrobials against all neonatal diseases as indicated below by using spectinomycin for joint ill.

> *"I have used spectinomycin for the first time and I haven't any cases of joint ill for the first time in years. It provides comfort."*

The routine use of prophylactic antimicrobials to avoid neonatal disease - and the negative emotions attached to it - prevent farmers from having experiences which challenge their perceptions of how these diseases can be controlled. That is, the underlying problem around neonatal disease control does not get resolved which exacerbates a long-term reliance on antimicrobials.

> *"I have used oral antimicrobials for years and it's great if you do it shortly after lambing…if I skip a lamb they usually get watery mouth."*

In some cases, farmers started using antimicrobials prophylactically with their veterinarian's recommendations due to an outbreak on the farm. After this, farmers continued prophylactic use in subsequent years, suggesting a new reliance on antimicrobials. The use of antimicrobials was initially used as a useful short-term strategy to avoid the problem of neonatal disease but then became a generalised and inflexible pattern of behaviour.

> *"We usually only had a handful of cases each year which was manageable. A few years ago, half way through lambing many lambs went down with joint ill. A third had to be put down, as there was no improvement. That year and ever since, we have given penicillin at 24 hours old and we haven't had a case since."*

This final category therefore illustrates that farmers often anticipate negative consequences if they do not routinely use antimicrobials in their lambs. This is sometimes spurred by previous experiences and the negative emotions surrounding this. Farmers use antimicrobials to avoid feelings of regret and minimise distress.

8.4.2. A theoretical framework for farmers' decision-making around prophylactic AMU in lambs

Through consideration of the results, a theoretical framework was produced to depict the constructs that act upon sheep farmers' perception of risk around the prophylactic use of antimicrobials in their lambs (Figure 13). Their perceptions of risk consequently influences the farmers' behaviour to either routinely use antimicrobials prophylactically or use antimicrobials only for treatment. Economic considerations, good farming identity, and perception of capability influence both the perception of risk around treating lambs with prophylactic antimicrobials and the risk around *not* treating lambs with prophylactic antimicrobials. Anticipated regret, negative emotions and experiential avoidance influences the perception of risk around not treating lambs with prophylactic antimicrobials. Whereas perception of social judgement influences the perception of risk around treating lambs with prophylactic antimicrobials. Economic considerations and perceived capability influence each other as the external perceptions of capability are caused by market demand.

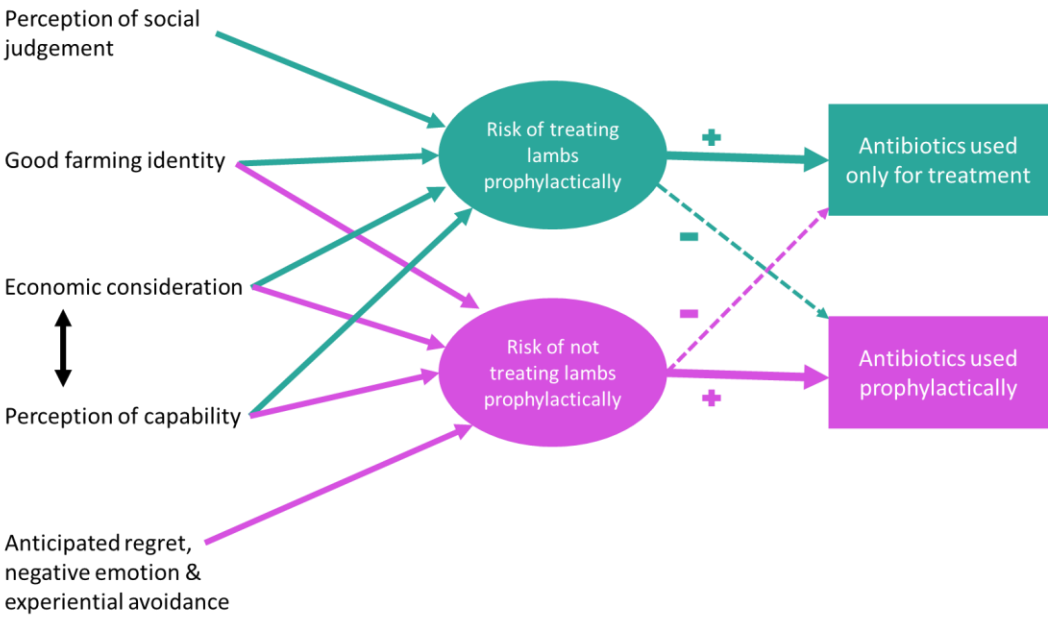


Figure 13: Theoretical framework based on grounded theory analysis for the prophylactic use of antimicrobials in neonatal lambs. The pink arrows refer to factors relating to the perception of risk around not treating lambs prophylactically. The blue-green arrows refer to factors relating to the perception of risk around treating lambs prophylactically. Plus signs indicate a positive influence on the outcome and minus signs indicate a negative influence on the outcome

8.4.3. Quantitative analysis: natural language processing content analysis

The scores for analytical thinking and authenticity were significantly lower in the study group compared to the control groups (P=0.01) (Table 30). Although there was no significant difference between groups for emotional tone, the score of emotional tone was below 50 suggesting greater negative emotional tone in the study group.

Table 30: Mean and median scores for the four summary language variables in the study group and the control groups, and the results from the Kruskal Wallis test and post-hoc Dunn's test

	Neonatal disease (N=111)		Grassland (N=108)		Weather (N=93)		Benjamini-Hochberg Adjusted p-value	Dunn's test
	Mean	Median (IQR)	Mean	Median (IQR)	Mean	Median (IQR)		
Analytical thinking	61.87	65.26 (48.92-79.61)	68.40	70.61 (56.34-83.57)	73.30	82.37 (61.17-93.26)	0.01	EP
Clout	48.77	49.17 (33.19-66.17)	48.88	50.00 (30.55-66.19)	47.27	46.55 (32.99-60.66)	0.81	-
Authenticity	47.46	48.27 (26.45-65.58)	61.77	65.74 (39.44-88.90)	73.94	85.21 (64.56-93.70)	0.01	EP
Emotional tone	42.85	37.41 (25.77-66.06)	51.55	47.90 (25.77-79.34)	51.71	51.03 (25.77-80.64)	0.08	-

EP= probabilities were different within each pair of forums groups

The relative frequencies of word categories for the study group (neonatal disease) and the two control groups (grassland and weather) along with the results for the Kruskal Wallis test with the post-hoc Dunn's test are presented in Table 31.

Table 31: Median and median relative frequencies of words used in the study group and control groups, and the results on the Kruskal Wallis test with post-hoc Dunn's test

	Neonatal disease (N=111)		Grassland (N=108)		Weather (N=93)		Benjamini-Hochberg adjusted p-value	Dunn's test
	Mean	Median (IQR)	Mean	Median (IQR)	Mean	Median (IQR)		
Function words (e.g. it, to)	51.30	51.63 (48.48-54.63)	51.17	50.88 (47.48-55.06)	46.37	45.95 (42.86-50.80)	0.01	W-G W-N
Conjunctions (e.g. and, but)	6.95	6.90 (5.56-8.24)	5.99	6.07 (4.52-7.55)	5.43	5.17 (3.77-6.98)	0.01	W-N G-N
Negations (e.g. no, not)	2.15	2.11 (0.96-2.92)	1.72	1.58 (0.00-2.76)	1.21	0.93 (0.00-2.17)	0.01	EP
Cognitive processes (e.g. cause, know)	14.55	13.38 (11.30-17.95)	11.72	11.18 (9.05-14.00)	8.09	8.57 (4.88-10.19)	0.01	EP
Social processes (e.g. mate, talk)	5.90	5.59 (3.57-8.16)	5.67	4.79 (3.03-7.81)	3.20	2.78 (0.00-4.61)	0.01	W-G W-N
Risk words (e.g. danger, doubt)	1.21	0.81 (0.00-1.82)	0.47	0.00 (0.00-0.49)	0.52	0.00 (0.00-0.51)	0.01	W-N G-N
Money words (e.g. cash, owe)	0.65	0.00 (0.00-0.91)	0.56	0.00 (0.00-0.85)	0.30	0.00 (0.00-0.00)	0.01	W-G W-N

W-N= probabilities were different within the weather group and the neonatal lamb group, G-N= probabilities were different within the grassland group and the neonatal lamb group, W-G= probabilities were different within the weather group and the grassland lamb group, EP= probabilities were different within each pair of forums groups

8.4.4. Integration of the quantitative and qualitative analysis

To integrate and report the results of the qualitative and quantitative analysis, a cross tabulation of results is presented in Table 32. The possible outcomes of convergent, complementarity, expansion and divergent results were assessed (Fetters and Molina-Azorin, 2019, Morgan, 2019). These are considered in detail in the discussion section.

Table 32: Assessment and integration of qualitative and quantitative results to understand farmers' decision-making around routine prophylactic AMU in lambs

	Qualitative results	Quantitative results
Convergent results	The decision-making is based on the consideration of two opposing types of risk: (1) the risk of not treating lambs prophylactically with antimicrobials and (2) the risk of treating lambs prophylactically with antimicrobials.	Frequency of risk words (e.g. danger, doubt) was significantly higher in the study group compared to both control groups.
	Economic pressures were considered for both types of risk.	Frequency of money words was significantly higher in the study group compared to the weather control group.
	Feelings of regret around not treating neonatal lambs prophylactically with antimicrobials puts emotional strain on the farmer.	Frequency of cognitive processes words was higher in the study group compared with the control group. Frequency of negations was higher in the study group compared with the control group. Emotional tone score was below 50 in the study group.
	Farmers who used antimicrobials only for therapeutic treatment in lambs felt a social and moral responsibility for appropriate AMU.	Frequency of conjunctions and negations were higher in the study group compared with the control group.
Expansion results	A farmers' perceived capability can influence their perception of risk relating to antimicrobials.	Frequencies of cognitive processes words, conjunctions and negations were significantly higher in the study group compared to control groups.
	Farmers who used antimicrobials only for therapeutic use in their lambs were influenced by social judgements.	Scores for authenticity were significantly lower in the study group compared to the control group.
	Farmers justified their prophylactic AMU through concepts of luck and uniqueness.	Analytical thinking scores were significantly lower in the study group compared to the control groups.
	There were conflicting perceptions of the good farming identity.	Frequencies of cognitive processes words, conjunctions and negations were significantly higher in the study group compared to control groups.

8.5. Discussion

To the author's knowledge, this is the first study to use NLP content analysis to understand farmers' opinions around AMU. Additionally, it is the first study in the veterinary field to integrate quantitative NLP data with qualitative data. The benefits of data analysis integration were of increased validity and completeness of the results and further insights into farmers' decision-making process. For example, perception of risk was identified in the qualitative analysis as an important factor influencing AMU behaviour. Analysis via NLP analysis showed convergent findings with an increased frequency of risk focus words when farmers were writing about AMU for neonatal disease compared to the control groups.

Integrating the analysis qualitative and quantitative data allowed for the generation of more meaning from the data and therefore enhanced the inferences made from the data. Whilst the qualitative analysis presented what was being said by the farmers, the quantitative analysis uncovered the underlying style and tone of the text. For example, social judgement was identified as an influence of risk perceptions in the qualitative analysis and the NLP analysis expanded this interpretation by identifying a guarded and distanced tone within the text. Furthermore, qualitative and quantitative data integration meant that more findings were identified than would be possible using either method alone. The conflicting good farming identities requires an in-depth understanding of the farmers values and experiences that can be achieved through qualitative analysis. The good farmer identities would unlikely to have been established in this research if NLP analysis was used alone.

This analysis showed that farmers were undertaking two types of risk assessment: (1) the risk of using antimicrobials only for treatment and (2) the risk of routine use of prophylactic antimicrobials in lambs. Key findings of this study include the disassociation of oral antimicrobials from other types of antimicrobials within the sheep farming field and the role of luck and uniqueness on farmers' perceptions of capability. These findings are discussed within the categories below.

8.5.1. Good farmer identity

How the farmer perceives their identity plays a key role in whether they routinely use prophylactic antimicrobials in all lambs or not. In both situations, farmers are trying to 'do a good job' (Zinn, 2017). There were a high frequency of cognitive process words, conjunctions, and negations in the study group compared with the control groups which reflect high cognitive complexity (Tausczik and Pennebaker, 2010). Cognitive complexity is a marker of debate such as recognising conflicting goals or alternative viewpoints (Brundidge et al., 2014, Wyss et al., 2015). Therefore, the high cognitive

complexity may be due to the debates around the conflicting good farmer ideals surrounding AMU.

'Good farming' draws on Bourdieu's concepts of cultural capital, habitus and field (Bourdieu, 1990, Bourdieu, 2011). The cultural capital refers to the symbols of social status. Embodied in cultural capital is habitus, which is the skills, habits and dispositions engrained through experience. The field refers to the particular sector in the social world that have their own set of rules to achieve cultural capital; sheep farming could be seen as its own 'field'. Good animal welfare is a recognised and accepted symbol of 'good farming' by farmers (Bellet, 2018), but responsible AMU may be a relatively new symbol that not every farmer has recognised yet.

The concepts of habitus and field may play a role in normalisation of routine prophylactic AMU in neonatal lambs. Farmers disassociated the use of oral antimicrobials for prevention from other types of AMU such as parenteral antimicrobials, where oral AMU was seen as more acceptable. This shows that using oral antimicrobials was considered a normal part of lambing time, and developed into a cultural norm. However, the rules of the game within the field of sheep farming are still developing and some farmers have started to question this practice. The cultural capital achieved through not routinely using antimicrobials prophylactically was a particular influence for those that see responsible AMU as a good farming symbol. These farmers have accumulated capital through perceived approval from people other than farmers, such as their veterinarian, consumers and policy makers. In other words, they have observed the injunctive norms surrounding AMU. This has allowed them to develop a new good farming symbol that incorporates both good animal welfare and responsible AMU.

The study also highlights how the rules of the game can change and how new good farming symbols can be established. It also shows how habits can be broken, and that use of prophylactic oral antimicrobials around lambing time can become 'de-normalised'. Some farmers talked about gradually reducing the use of prophylactic antimicrobials over time and realising that this did not have any negative consequences. Through learning and routinizing the practice of not using prophylactic antimicrobials, their concept of what is considered risky shifted. As they gradually reduced their prophylactic use, they learnt that this risk of not using prophylactic antimicrobials in their lambs is not as high as expected. Through this gradual exposure, they were re-learning that there was a one to one link between not using antimicrobials prophylactically and good outcomes.

8.5.2. Economic constraints and the impact on perceived capability

The economics of prophylactic AMU was considered on both sides of the risk argument. Words related to money were used more frequently in the study group compared to the weather control group. The qualitative analysis

revealed that in the short term the use of antimicrobials for prevention of disease was thought to reduce production losses. However, in the long term, a reliance on cheap antimicrobials may cause AMR and therefore a need for more expensive antimicrobials or even lamb deaths. As AMR is perceived as an issue which will be encountered long into the future, some farmers consider this to be less important than the challenges they face in the present (temporal discounting). Farmers may value the present certainty of healthy lambs more than the uncertain future positive effect of preventing AMR.

There were also external economic constraints impacting on the way in which farmers carried out management practices, which in turn could affect the levels of disease in the flock. Sheep farms typically have a much lower business income than other types of farming in the UK such as dairy, poultry, and arable (DEFRA, 2019a). Much like in lower income countries, sheep farmers are restricted by economic and biological margins which may result in reliance of antimicrobials (Hinchliffe et al., 2018).

These external economic constraints of sheep farming were shown to impact farmers' perceptions of being able to control neonatal disease. Although all farmers recognised that good hygiene practices may prevent neonatal disease, these were often seen as not practical to always implement. Thus, at the height of lambing season, farmers may lose the psychological or physical capacity or capability to engage in good hygiene practices; turning to prophylactic antimicrobials to regain control over the situation. Capability is one of three necessary conditions for a volitional behaviour to occur (Michie et al., 2011). In the quantitative analysis, a significantly higher amount of cognitive words, conjunctions and negations highlight that farmers' cognitive load is higher which may impact their psychological capacity (Tausczik and Pennebaker, 2010).

However, there were cases where not all of the credit for preventing neonatal disease was attributed to the farmers' ability. Some farmers expressed that having healthy lambs without using antimicrobials was not solely credited to the farmers' skill but also to luck. The findings show that farmers clearly distinguish between fate, chance, and luck. Some farmers were seen as just unlucky and this indicates that for them, interventions are less likely to be perceived as effective as they attribute negative outcomes to their bad luck. Likewise, if farmers believe that diseases are due to chance – and thus uncontrollable – then it is much harder to convince them that change in behaviour or policy will make a difference.

There was also another related concept of a farms 'uniqueness' that emerged. Farmers may be equally skilled but the uniqueness of their farm might mean they are not as capable to prevent neonatal disease. The perception of uniqueness on sheep farms has already been reported by Kaler and Green (2013). They suggest that a lack of records and on-farm data collection adds

to this perception of uniqueness, as farmers are not able to compare each other. Indeed, this might also be the case for sheep farmers' comparisons of AMU as there is currently a lack of data around AMU in the sheep sector (Doidge et al., 2020c, RUMA, 2020). This perception of uniqueness of every farm could possibly explain why the scores for analytical thinking were lower in the study group compared with the control groups (Pennebaker et al., 2014).

8.5.3. Anticipated regret, negative emotions and experiential avoidance

There was a largely emotional element to the motivation for the prophylactic use of antimicrobials identified in the current study, a construct not widely researched or reported in farmer decision-making. Previous experiences, where lambs have died as a result of potentially preventable diseases such as watery mouth and joint ill were leading to such emotional motivation. This is an example of volition in risky behaviour (Nordgren et al., 2007). The choice to use or not use antimicrobials prophylactically in lambs is a voluntary risk. Therefore, if a negative outcome occurs because the farmer has chosen not to use antimicrobials prophylactically, the farmer will feel personally responsible for the deaths and this leads to regret. Farmers can anticipate the threat of regret, which leads to reduced tendency for risky behaviour. The risky behaviour in this case is not using antimicrobials for prevention of disease in lambs.

Farmers attempted to avoid the negative experiences and feelings associated with preventable neonatal disease through the use of prophylactic AMU, which could be an example of experiential avoidance (Hayes et al., 1996). Experiential avoidance has been linked to certain behaviours such as poor physical activity, as well as various forms of psychopathology, for which interventions such as exposure therapy may overcome (Kashdan et al., 2006, Newman and Llera, 2011). In exposure therapy, patients are exposed to the feared emotional stimuli in a graduated manner. The exposure could be to an object, situation, or activity. For farmers with experiential avoidance, the exposure would be to the distressing situation of not using antimicrobials prophylactically in their lambs. The findings do not suggest there is a direct linkage in our study population with this construct, but it raises the possibility of its role and especially techniques such as exposure therapy that could to be used for changing behaviour of routine prophylactic use. In this study, there were accounts of farmers gradually reducing their AMU over their lamb crop to successfully discontinue their habitual prophylactic use of antimicrobials without causing excessive distress to the farmers. This has similarities with exposure therapy as farmers were progressively exposed to the fears and worry of not using antimicrobials prophylactically. This may be an effective strategy for behaviour change that could be investigated in the future.

There was also a lower emotional tone score for the study group compared with control groups which suggests a negative emotional state. Other word categories within the LIWC dictionary may be additional identifiers of a negative emotional state. For example, use of negations was negatively correlated with indicators for positivity (Hancock et al., 2007, Pang et al., 2020). The high frequency of negation words used by contributors in the neonatal lamb threads may be indicative of their low mood due to anticipated regret.

8.5.4. Perception of social judgement

Farmers who did not use antimicrobials for prevention in their lambs were aware of the social implications around the risk of antimicrobial overuse. For these farmers, the motivation for limiting AMU was their perceived judgement from society. The farmers also felt a moral responsibility to ensure they were using antimicrobials appropriately. When people describe pursuing a duty or something they ought to do, they use more exclusive words such as negations and conjunctions (Vaughn, 2018). Therefore, the high frequency of conjunctions and negations in the neonatal lamb posts could be explained by farmers' feelings of social or moral duty around their AMU.

The farmers appeared aware that the forum was publicly available and were concerned that members of the public could see other farmers expressing a reliance on antimicrobials. This may be one of the reasons why the scores for authenticity were lower for the study group compared to the control groups. The lower score suggests a more guarded discourse, perhaps because of the farmers' fear of social judgement.

Farmers who used prophylactic antimicrobials in their lambs were perhaps less susceptible to the social pressures around reducing their AMU. They avoided or dismissed conversations around AMU with their veterinarians. Previous studies have shown that promoting disease prevention to farmers can be difficult for farm veterinarians (Ruston et al., 2016). For farmers who are not susceptible to social pressures, it may be useful to target the other constructs identified in this study, such as experiential avoidance and perceived capability, to improve their antimicrobial stewardship.

8.5.5. Limitations

The use of data from online forum posts means that the study findings were restricted to farmers with internet access who were aware of the farming-based discussion forum. The demographics of farmers in this study were unable to be obtained. The naturalistic, unobtrusive approach to data collection meant there was an inability to ask for elaboration or clarification of points made by forum posters. However, this approach was likely to result in less social desirability bias than interview or survey data collection methods.

Some of the results of this study, such as the normalisation of oral antimicrobials, may only be applicable to sheep farmers in the UK as this may be a cultural phenomenon. These findings need to be investigated further with different farming sectors and countries to understand whether the results are transferable across settings.

8.6. Conclusions, research and industry Implications

This study used method triangulation of discussion forum posts to understand farmers' decision-making around prophylactic AMU in lambs. Farmers must consider two opposing risks in the decision to use antimicrobials in neonatal lambs: (1) the risk of only using antimicrobials in neonatal lambs for the treatment of disease and (2) the risk of routinely treating lambs with prophylactic antimicrobials. These risks were influenced by their economic considerations; perception of social judgement; perceived capability; anticipated regret, negative emotions and experiential avoidance; and their good farming identity.

In terms of research implications, the study presented reasons why farmers perceived risks of not treating lambs with antimicrobials as high, which included some previously identified constructs such as lack of psychological or physical capacity or capability to control neonatal disease, and economic constraints. Constructs relating to concepts of luck and uniqueness mean that farmers may not adhere to best practices for the prevention of neonatal disease. This suggests that farmers need personal advice on their AMU rather than relying on the sector-wide information sources that are currently available.

On the other hand, the research also provides evidence of how farmers have successfully stopped their prophylactic use habits. Gradual exposure to more responsible AMU during lambing time may help to counteract farmers' experiential avoidance. Additionally, the research shows that judgement from consumers and authorities was an important factor in these farmers perception of risk around using antimicrobials prophylactically. Appropriate or responsible AMU was an important part of their identity as a good farmer. Prophylactic AMU could be reduced through developing an increased recognition of appropriate AMU as a symbol of good farming. For successful behaviour change, it is particularly important to de-normalise the use of prophylactic antimicrobials around lambing time as there is a currently a disassociation of oral antimicrobials from other types of antimicrobials within the sheep farming field. These results can be used to inform knowledge exchange and intervention strategies around prophylactic AMU in lambs to improve antimicrobial stewardship in the sheep farming sector.

9. Study 7: Farmers' perceptions of preventing AMR on sheep and beef farms: risk, responsibility and action

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Author contributions:

CD, AR, and JK contributed to conception and design of the study and the themes generation. CD performed data collection. CD and AR performed analysis of transcripts. CD conducted the writing, AR and JK made some contributions to the writing, reviewing and editing. CD wrote the entire content of this chapter. FL, CH, and LK contributed to the manuscript revision and interpretation of data. All authors read and approved the submitted version.

9.1. Abstract

AMR is one of the most serious public health risks facing humanity. The overuse of antimicrobials in the treatment of infectious disease have been identified as sources of the global threat of AMR. This study examines how farmers perceive and manage risks associated with overuse of antimicrobials. Specifically, the study examines the role of habitus and risk in determining farmers' decisions to adopt national antimicrobial reduction targets set by members of RUMA. Semi-structured interviews were conducted with 34 sheep and beef farmers in England and Wales. Farmers presented four scripts which illuminated reasons for limited adoption of the targets. The scripts presented the farmers as 'good farmers' facing an emerging threat to their ontological security. Scripts suggested that they engaged in preventative measures but deflected responsibility for reducing AMR to veterinarians and poorly run farms. This research provides valuable insights for policy makers and highlight the benefits of including social science research to support effective implementation.

9.2. Introduction

Antimicrobial resistance has been identified as one of the most serious public health risks facing humanity (World Health Organisation, 2014). Risks posed by the overuse of antimicrobials in the treatment of infectious disease, in both humans and animals, have been identified as sources of this global

threat (O'Neill, 2016). To support decisions on the most effective risk reduction strategies there have been calls for greater consistency, standardisation, granularity, and validation of surveillance data collected on AMU and AMR (Parliamentary Office of Science and Technology, 2019)

UK policy responses have focused on the setting of national targets to reduce overall use of antimicrobials and on implementing restrictions on some antimicrobial drugs (Tang et al., 2017, Helliwell et al., 2019, Morris et al., 2016). The use of targets to reduce AMR is based on the precautionary principle. The precautionary principle offers a solution to the problem of coping with the mixture of limited knowledge and ethical doubts with respect to the uncertain impact of technological developments, particularly in the fields of the environment and health. As such it provides a systematic way of coping with the irreducible uncertainties of decision-making and thereby providing legitimation for policy (Osimani, 2013). In the framing of public policy governments make risk choices, for example, the UK policy response to a range of food and environmental risks such as BSE, and *Escherichia coli* outbreaks has been risk averse with risk framed as contingent and uncertain (Kemshall, 2001). It has been suggested that the consequence of this approach, within the context of AMR in agriculture, is that governments avoid risk by shifting responsibility to the farmers and veterinarians who become accountable for risk assessment and management (Kemshall, 2001).

The UK Government has published policies which have sought to set targets for the reduction in use of antimicrobials in animal production (VMD, 2019, Parliamentary Office of Science and Technology, 2018). This drive to ensure responsible use of antimicrobials in agriculture has been led by RUMA. RUMA is an independent alliance made up of many organisations representing different livestock sectors and stages of the food chain. The group was set up in 1997 with the aim of promoting best practice in animal medicine use. In response to the increasing concerns around AMR, they identified areas where AMU could be reduced, refined, and replaced without compromising animal health and welfare (RUMA, 2017). The RUMA guidelines state that all farmers have a responsibility for the health and welfare of the animals under their control and that they must take joint responsibility, with their veterinarians, in the discharge of correct and appropriate antimicrobial treatment and care (RUMA, 2017). They are accompanied by a set of industry-developed species-specific AMU targets for eight key UK livestock sectors. In particular, the sheep and beef sectors have identified a number of challenges to achieving target reductions including: no central or uniform system to collect data; low veterinary involvement on farms; difficulty collecting on-farm data; separating usage between species and possible complacency within the sector, as many farms are extensive with a low numerical usage. As a result, RUMA provided sector wide targets for the sheep and beef industry which included the target to reduce AMU levels by 10% between 2016 and 2020 (RUMA, 2017).

9.2.1. Risk concepts in social science

Decision-making requires us to consider actions that differ in their level of risk. Risks are something (e.g. a person, object or event) that is considered an incipient danger or threat (Lupton, 2013). When making a decision, greater expected return makes choosing an option more attractive; whereas greater perceived risk makes an option less attractive (Figner and Weber, 2011). Thus, there is a trade-off between the risk and benefit. Often, individuals choose the safest option, even when the risk may have higher expected benefit which is called risk aversion. This can be influenced by a person's familiarity to a situation. When an event is familiar and frequent, people consistently underestimate the risk. Conversely, when an event is infrequent but has high consequences, people often overestimate the risk. How much a person perceives a risk or benefit is subjective and this may be affected by the outcomes of previous decisions, or how ambiguous the outcome is in the situation (Post et al., 2008). Decision-making becomes risk-taking when the possible outcomes of a choice are judged as severe and the decision maker involved will be affected by the outcomes (Zinn, 2017). Judgement on what is considered a risk is constructed by the social and cultural context through interactions with bodies, material objects and spaces (Lupton, 2013).

Risk judgements can be rational or non-rational. Rational judgements are based on knowledge and calculation and often limited to experts. Non-rational methods for risk judgements include hope, faith, and ideology are typically used when a person has lack of control over a situation (Zinn, 2016). Zinn (2008) describes a third type of risk judgement – the in between strategies that are neither wholly rational nor irrational. These include trust, emotion, and intuition. Lay people and experts use in between strategies to make risk judgements in their everyday life. Lupton (2013) argues that emotions and risk judgements are fluid, shared, and collective. She labels the interaction between emotion and risk an emotion-risk assemblage. This interaction between risk and emotions means emotions are present in all types of decision-making – rational, irrational and stages in between. Whilst emotions may always be part of a decision, they may not always be at the forefront of the decision. Instead, they may supplement or support other rational, irrational or in between strategies (Zinn, 2016).

Zinn (2017) reviewed the existing body of risk research to systemise the sociological domains of risk-taking behaviour into control, motives, reflexivity and identity. Risk-taking can depend on the level of *control* a person has or perceives. They may take risks in order to regain control of a situation, or to confirm their level of control over a situation. Level of control is often entangled with trust where social relationships are involved. Peoples risk-taking can be driven by their social *motives* such as feelings of excitement, feelings of self-worth, or in response to vunerability. *Reflexivity* refers to embedded human belief structures rooted in the social world including

habitual risk-taking, routinised risk-taking or normalised risk-taking. Finally, a persons social *identity* can be key to explaining their risk-taking. People may take risks in order to develop their identity, their identity may shaped what risks are deemed acceptable to take, or they may take risks to protect their identity.

Understanding the sociological concepts of risk-taking behaviour related to a farmer's decision to use or not use antimicrobials is important. This is because producing policies without knowing the social processes involved in a risk behaviour usually results in an unsuccessful outcome. For example, many policies and behaviour-change interventions focus of the concept that individuals are undertaking a particular risky behaviour because they have a distorted perception of the risk. Thus, campaigns tend to centre on educating persons about this risk in the aim to correct this distorted perception (Harries, 2008). However, many of these campaigns fail as individuals already know the risks involved, and why they take these risks is not necessary under individual control. They focus on the individual, and ignore the social and environmental contexts involved (Glanz and Bishop, 2010). It would, therefore, be sensible to consider farmer risk-taking regarding AMU from a sociological perspective.

9.2.2. Risk as part of farmers habitus

Bourdieu's theory of practice has been applied to antimicrobial prescribing in human medicine (Broom et al., 2014) and anthelmintic use in farming (Bellet, 2018). Society contains many fields, for example the physician or farming professions can be seen as their own field. Within each field, there are certain types of social game. Habitus refers to the social norms that guide behaviour or thinking which are attained through integration into social groups such as social class, profession or gender. In other words, habitus is their 'feel for the game' (Bourdieu, 1990). When an individual follows the rules of the game they gain capital. The more capital an individual has, the more powerful position they have within their field.

Broom et al. (2014) analysis of antimicrobial prescribing in human medicine revealed that doctors' habitus meant that sub-optimal prescribing practices often occurred. This is because the rules of the game within the medical field were not focussed on AMR. Instead, the rules aimed to protect the patient, manage time pressure and secure social capital. Similarly for anthelmintic use in farming, deworming practices were shaped by farmers' habitus to achieve economic and symbolic capital (Bellet, 2018).

Bourdieu's concepts of field, habitus and capital have been use to develop the good farmer construct (Sutherland and Burton, 2011, Sutherland and Darnhofer, 2012, Butler and Holloway, 2016, Bellet, 2018). The establishment of the good farmer construct within rural sociology refers to the symbols and ideals set in farming culture that farmers must practice in order to gain social standing (Burton, 2004). Good farming can be exemplified through sound

stockmanship, having the skills to assess animal wellbeing and/or disease status, and by assessing and managing risk to animal health (Shortall et al., 2018).

This study builds on the relationship between risk and habitus to gain an understanding of sheep and beef farmers' decisions and actions relating to reducing AMU, in order to support successful behaviour change, policy implementation and the reduction in the risk of AMR.

9.3. Methodology

Semi-structured interviews were conducted with farmers on thirty-four farms of which eight were beef-only, four were sheep-only, and twenty-two were mixed species farms (See Table 4 in Section 2.4.1 for farm regions and size).

Farmers who took part in the quantitative study and agreed to be interviewed were contacted by phone to arrange a suitable time for interview. All interviews were conducted on the respondents' farms and fieldwork took place between July 2018 and December 2018. The interviews were conducted by CD, were digitally recorded and then transcribed verbatim.

The semi-structured interview guide (Appendix 11) was informed by the literature on risk and decision-making (Zinn, 2017) and target setting as a means of influencing behaviour change (RUMA, 2017). The aim of the interview schedule was to consider farmer risk-taking regarding AMU and resistance using the sociological domains presented by Zinn (2017). Not all of these domains may be relevant to risk-taking regarding farmers AMU or resistance. Instead, we can aim to identify which of these domains are relevant through asking broad questions relating to AMU and resistance. The topics covered in the interviews included general farm practices, AMU, perceptions of current AMU, national reduction targets, perceptions of the risk of AMR, AMU on other farms and perceived responsibility of AMU monitoring. During the discussion of targets for AMU, a show card was used to indicate the national 10% reduction target set by the RUMA Targets Task Force for the sheep and beef sectors (RUMA, 2017).

The transcribed data was coded using the constant comparative method (Maykut and Morehouse, 1994) to identify emerging categories of data. Analysis was supported by the use of NVivo (NVivo qualitative data analysis Software; QSR International Pty Ltd. Version 12, 2018). Validity and reliability was established through rigorous record keeping, reporting of data collection, analysis and then verification of findings by two researchers with transcripts being read and re-read by two researchers CD and AR. The researchers' analysed the data in matrices for each respondent until data saturation was achieved. There were three steps to the coding process: initial coding, focussed coding and theoretical coding. Initial coding was the first step where many codes are produced. Focussed coding then narrowed down the number

of codes by selecting the most suitable ones. Finally, connections were made between codes to produce categories. Categories were then related to each other to establish a script. Enticott and Vanclay (2011) describe scripts as a unique sequence of actions that define a well-known situation – scripts are learned through people's perceptions of the regular and repeated features of the world. Sociological scripts stress the flexibility and capacity of the script writer to learn and update them thus in making sense of a particular situation people develop appropriate roles for themselves that match the given situation to their actions (Enticott and Vanclay, 2011).

The scripts were then used to assess the RUMA targets set for the sheep and beef sectors. This was based on recommendations from a policy analysis of target setting in the National Health Service (NHS) (Berry et al., 2015). The policy analysis introduced five tests that must be met for targets to be appropriate and effective. If these tests are met then target-setters are more likely to achieve the desired outcome. The scripts were evaluated against these five tests to understand how RUMA targets can be more effective in the future and consequently aid behaviour change around AMU.

9.3.1. Ethics

All farmers read an information sheet and signed a consent form before participating in this study. Please see Appendix 1 for a copy of the information sheet and consent form. The study was approved by the University of Nottingham School of Veterinary Medicine and Science Ethics Committee (no 1850 160916) (Appendix 2).

9.4. Findings

Scripts have been described as moral resources used by farmers to account for and justify their management of disease and as a means of farmers re-constructing their identity (Vanclay and Enticott, 2011). They are situationally contingent and socially constructed (Enticott and Vanclay, 2011) and have been described as a culturally shared expression, story or common line of argument which provides an explanation for a particular course of action. Respondents articulated four main scripts or lines of argument when discussing their management of the risk of AMR on their farms:

- AMR – the script of an emerging threat
- Good farmer habitus – the script of experienced, knowledgeable farmers
- Adopting preventative measures – the script of controlling risk and adopting the precautionary principle
- Taking responsibility for risk – the script of risk, defence and othering

9.4.1. Antimicrobial resistance – the script of an emerging threat

When asked about their current use of antimicrobials respondents reported administering antimicrobials for a wide range of problems. In sheep these

included mastitis, lameness, watery mouth, abortion, joint ill and navel ill. In beef, antimicrobials were mainly used for respiratory disease, lameness and eye infections.

Given the range of infections that were being treated with antimicrobials respondents were asked about the potential of developing AMR on their farms. When addressing this question they amplified the potential risks associated with AMR identifying factors that had the potential to risk not only their reputation as a good, profitable farmer but also to the health and wellbeing of their animals:

> *"Well, it could end up catastrophic! I suppose because if you can't treat something that spreads and gets out of hand, I suppose you move onto the antimicrobial so you're moving up the ladder all the time onto more expensive drugs, yeah I mean… it'll be bad for both animal and for pain wise, it'd bad for the farmer financially, won't it?"* Respondent 26 (Sheep and beef farmer)

AMR was perceived as a potentially catastrophic risk that would need ongoing risk assessment and management to protect the animals and their livelihoods.

Twelve respondents also expressed fears that they may already have observed signs of resistance on their farms and over half felt they were at high risk of developing resistance given they had encountered difficulties in treating infectious diseases in their animals:

> *"When we used to have bottles they'd last for… they'd go out of date before we use 'em, now it's sort of when you start to use 'em you use 'em and 20% of times you use 'em they just don't have effect now we're starting to see; the antimicrobials haven't got the fight power against the disease what they used to have.*" Respondent 2 (Sheep and beef farmer)

Their scripts suggested that the spectre of AMR was challenging their sense of identity as a good farmer undermining their confidence in their ability to identify and treat infections with certainty and challenging their ontological security i.e. their sense of continuity and order in life (Ruston, 2009, Jaeger et al., 2013). They reported that they were sometimes unable to determine whether they had wrongly identified disease or were subject to AMR:

> *"And they haven't cleared up, but I don't know if that's resistance or not or just I'm probably assuming it's one type of lameness and it's another type that that antimicrobial isn't, yeah. So no, I don't know if we've got any resistance to be honest."* Respondent 21 (Sheep farmer)

Respondents were concerned that rising AMR due to inappropriate use in the industry may cause restrictions on what and how antimicrobials were used on farms. This posed a threat to the farmer's way of life and the welfare of their

animals. Farmers felt that it could get to the stage where only veterinarians could administer drugs to the animals on their farm. This could cause a breakdown in the trust between farmers and veterinarians, or not allow trust to develop to begin with.

"But it's going to get very awkward when it's lambing time and you need Pen & Strep or something for a ewe with a difficult lambing and you've got to go all the way down to (town) and get it in a syringe and bring it all the way back again. That's the death of farming. They've got to trust us." Respondent 15 (Sheep and beef farmer)

Farmers were also concerned that rising AMR within the sheep and beef sectors could damage the public perception of agriculture and consequently they could face blame for AMR in humans.

> *"It's also the public perception of agriculture as a whole; if we're seen as a hotbed for developing resistance to antimicrobials how long is it before that transfers to a human population?"* Respondent 31 (Sheep and beef farmer)

Overall, respondents presented a story of a major risk or threat to the health of their animals which was changing their relationship with risk, undermining their confidence in their ability to manage the risks encountered and threatening their ontological security – that is their sense of continuity and order in life and in the consistency of the surrounding social and material environment (Jaeger et al., 2013).

9.4.2. Good farmer habitus – the script of experienced, knowledgeable farmers

Habitus is developed in dialogue within context and on the rules of the game, which is certain rules they have the play by to gain cultural, social and economic capital and is subject to change over time (Sutherland and Darnhofer, 2012).

Most respondents reported that they felt that they had the skills to identify infections and administer antimicrobials or common conditions that they encountered, such as pneumonia or footrot. They argued that they were experienced stockpersons and capable of assessing symptoms, identifying the disease and deciding on a course of appropriate action. They reported that their assessments drew on their intuition, situated knowledge and experience to assess risk to the health of the animal:

> *"Well, if you've been around animals for long enough and if you've been brought up on a farm most farmers can identify a sick animal at a first glance. Yeah. You only need to look at their ears and eyes really, and the way they walk."* Respondent 11 (Sheep and beef farmer)

They suggested that most of the time their knowledge and experience was sufficient for them to decide if antimicrobials were needed and that their confidence levels in terms of using antimicrobials were high:

> *"I feel very confident that I know when (to give antimicrobials) 90% of the time I'll know when to use them and the 10% of the time I am unsure I have full confidence in my vet."* Respondent 11 (Sheep and beef farmer)

The treatment of common animal illnesses such as lameness and pneumonia were constructed as an ordinary event and part of the everyday activities on farms. The identification and treatment of such common diseases was learned through their upbringing on farms and embedded in the cultural knowledge of farming:

> *"Antimicrobials, just footrot in sheep, this time of year it's one of my biggest tasks probably doing sheep work; every time you get a bunch in there's always a sheep lame."* Respondent 17 (Sheep and beef farmer)

> *"**P2:** You're always going to get lameness.*
>
> ***P1:** You can identify the lameness so I suppose you'd have to say lameness. You get other things crop up from year to year but lameness will always be… or is always just an underlying one."* Respondent 22 (Sheep farmer(s))

Farmers considered they were experts in identifying and treating common diseases. They felt that treatment practices had changed very little over time and that it was very rare they would encounter a disease that was unknown to them. Hence, they seldom called their veterinarian out to visit the farm.

> *"There's no new real need for them to come out to sheep… You know, if you have a lame sheep you know what it is and we've had vets in the past tell us what to do so it doesn't really change."* Respondent 10 (Sheep and beef farmer)

Farmers believed that their veterinarians trusted their capabilities to identify and treat their animals. For example, one farmer expressed that their experience as a farmer meant that their level of knowledge on their animals' health was on par with less experienced veterinarians.

> *"I had a cow last year in the cubicles, she was unwell, she got quite irritable and I rang up the vets and said, 'Look, I don't know what this is.' The head vet came out, the senior vet because he said, 'You know, if you don't know what's going on then there's no point in sending one of the junior vets."* Respondent 13 (Sheep and beef farmer)

Respondents painted a picture of themselves as self-assured, competent and highly experienced farmers who were capable of managing disease risks appropriately. They were able to draw on a range of internal resources to support their decisions. Such resources were part of a collective of skills and expertise acquired as part of their habitus.

9.4.3. Adopting preventative measures – the script of controlling risk and adopting the precautionary principle

Shortall et al. (2018) suggest that farmers will strive to be 'good farmers' according to the rules of the game – which in the case of reducing AMR would be minimising the use of antimicrobials. Early literature on good farming indicated that farmers could be resistant to changing their ideas and ways of working (Sutherland and Darnhofer, 2012). Their habitus and their cultural capital (in this case ability to identify infection and administer antimicrobials) ensured that their behaviour remained consistent and unchanged. However, when facing new risks that potentially threaten their animals, their livelihood or ontological security (as a good farmer) farmers will change their attitudes and re-negotiate perceived good farming standards (Shortall et al., 2018).

It was evident that respondents feared developing AMR believing it would have an extremely detrimental effect on their businesses and their animals. For farmers their farm work represented a central aspect of their life. Any changes to their routine practices needed to be considered carefully:

> *"It isn't a case of them feeling that by doing something might risk their business and in farming risking the business is also risking their life, so the consequences are far greater in farming."* Respondent 24 (Sheep and beef farmer)

The prospect of AMR was considered risky enough for farmers to start adopting new practices to minimise this risk. They reported using alternative practices in order to protect their animals and reduce the need for antimicrobials. They had begun to think about or use alternative strategies for managing disease on their farms. Strategies they reported included improving biosecurity and managing animal health.

Farmers reported managing animal health by using alternatives to antimicrobials including vaccines to prevent disease, anti-inflammatory drugs to aid with pain relief and culling to avoid breeding genetically prone animals and stop disease spread:

> *"Vaccines as much as you can. That's our theory. I know people say they cost a lot of money but just so much pleasanter if they're not ill, isn't it?"* Respondent 26 (Sheep and beef farmer)

> *“Sheep wise I think you have got to cull the worst ones, possibly the carriers of any disease, footrot and things like that…"* Respondent 30 (Sheep and beef farmer)

> *"Cause I use anti-inflammatories as well so I try and cut down the use of antimicrobials by using anti-inflammatories to help and hit ‘em hard in one go rather than continuous use of antimicrobials."* Respondent 3 (Sheep and beef farmer)

In some cases it appeared that efforts to keep AMU to a minimum had a negative impact on animal welfare. This was particularly the case for the treatment of lameness in sheep. Although prompt treatment of all sheep with footrot with injectable antimicrobials is recommended by industry (AHDB, 2020b), some farmers were only treating severely lame sheep with injectable antimicrobials.

> *"We only use antimicrobials for the ones with maggots in ‘em and the hoof falling off."* Respondent 29 (Sheep farmer)

> *"Footrot is the major bugbear but like I said, we inject if they’re really, really bad, if not you just trim and spray it and put ‘em through a footrot bath. Yeah, we’re not ruthless with it."* Respondent 30 (Sheep and beef farmer)

Respondents presented a picture of themselves as farmers who were actively engaging in preventative measures, who were signed up to the ‘precautionary principle’ as a way of managing risks associated with infections amongst their animals. Nevertheless, the strategies mentioned did not appear to be part of a coherent plan to manage risk but rather a risk reduction menu from which they could choose a risk reduction option. In adopting these strategies they sought to maintain their sense of ontological security, their self-identity as a good farmer

9.4.4. Taking responsibility for risk – the script of risk, defence and othering

When respondents were asked if they considered the specific reduction aims within the RUMA targets to be feasible for sheep and/or beef farmers - they identified a range of challenges that they might face in attempting to achieve the targets. Though the RUMA targets are for sector-wide AMU and are aimed at a national level, most respondents reflected on this through their own individual farm use.

The notion of having to reduce their AMU by 10% was not an idea that resonated with respondents as they believed that their usage was already lower than the target set. They provided a number of justifications for challenging the idea that they needed to reduce their use and for deflecting responsibility to others.

They defended their position as very low users of antimicrobials who had already made such changes and argued that they would not be able to successfully reduce them any further.

> "*Reduce mine – I don't think I could reduce it much more than I'm doing because I would say I'm probably using a very, very small percentage to most sheep farmers already because we've stopped using it*." Respondent 34 (Sheep farmer)

> *"Well, 10% of a lot would be achievable but when you don't use a lot I think it becomes more difficult."* Respondent 13 (Sheep and beef farmer)

Antimicrobials were reported as being used as a last resort or only in emergency situations so any attempt to further reduce their use further would put their animals' health and welfare at risk:

> *"I couldn't really reduce it at all without losing stock- I only really use antimicrobials when an animal is ill so it would result in loss of animals."* Respondent 4 (Sheep and beef farmer)

> *"Well, we only use them when they're necessary so you're gonna have problems with disease spreading and having a worse problem."* Respondent 8 (Beef farmer)

The alternative of risking further or ongoing disease amongst their animals was not a risk that they could justify. Nor was a potential risk to their reputation that could result from allowing sick animals to remain untreated. Such action was considered irresponsible in terms of animal health. Their responses appeared to be based on an emotional attachment to their animals and a fear that they could be seen as irresponsible or bad farmers:

> *"It doesn't look very good 'cause we've got a lot of footpaths and there's always somebody looking over the fence so you've gotta be careful what you do and it's in the best interests of the animal to be healthy and walking around on four legs instead of three."* Respondent 2 (Sheep and beef farmer)

> *"I do worry that people looking from the outside say, "Actually, he's got lame sheep there, he's not treating them"."* Respondent 17 (Sheep and Beef farmer)

Respondents reported additional challenges that they felt would prevent them from protecting their livestock. They suggested that they did not necessarily know the risks they were taking when 'buying in' animals that were sick or carrying resistant organisms and this made it more difficult for them to optimise or reduce their AMU for newly purchased animals due to a lack of information about their disease and treatment status:

> *"Livestock is moving between farms all the time so you don't know what you are buying in when you buy breeding stock, so yes, I mean it is a concern yes."* Respondent 6 (Sheep and beef farmer)

> *"I wouldn't know that, would I, 'cause you don't get a history of what animals are treated with when they come."* Respondent 19 (Beef farmer)

Importantly, trying to interpret and measure progress against the targets, particularly without knowing their baseline usage was considered outside their remit or skill base so they would not be able to meaningfully reduce the risk associated with over use of antimicrobials:

> *"So as a farmer I don't know what 10 milligram per PCU means."* Respondent 14 (Sheep and beef farmer)

> "*I don't think everyone knows what we are using now to be able to reduce it by 10%. I don't know how you're gonna use the target you've got at the moment 'cause we haven't really got a baseline target at the moment."* Respondent 5 (Beef farmer)

Having to interpret statistics so they could reduce their AMU by 10% would act as a barrier to change and potentially be at odds of their habitus and their concept of themselves as good farmers who prioritise the wellbeing of their animals and the viability of their farm. A lack of evidence or information about how the targets were being measured prevented them from being able to decide if they were contributing to achievement of the national target to reduce usage. They reported feeling unable to fully understand the nature of targets and how to turn them into action. In such circumstances, it was difficult to 'own' the targets and they sought to locate responsibility for achieving them with others.

9.4.4.1. Othering

Given the challenges respondents reported in attempting to reduce AMU they sought to shift responsibility for the achieving the targets and blame for not achieving them on to others. Othering involves defining or defending self-identity by distancing oneself from individuals or other groups who are excluded or regarded as posing risks to self-identity (Ruston, 2009). Individuals use social skills and their judgements of situations and especially of others, which might be based on hearsay or intuition and shaped by shared experience or habitus (Crawshaw and Bunton, 2009). Perceptions of risk among people sharing the same cultural context are related to the groups' legitimising moral principles - thus 'others' are often identified as threatening the mainstream (Ruston and Smith, 2013).

Farms that overused antimicrobials were framed as poorly run and held responsible for increasing the risk of AMR:

> *"Poor management. Simple as. Not knowing what they're doing properly. Probably not seeking professional advice through their vets."* Respondent 21 (Sheep farmer)

> *"Too high a stocking densities, mixing of age groups within buildings, unvaccinated animals coming, where they haven't got a clue where they've come from, poor hygiene and general standards so cattle aren't looked after well… full of rats and other things and various things that can spread disease and issues. Blanket antimicrobial treatments and stuff like that."* Respondent 1 (Beef farmer)

In describing poorly run farms as problematic, respondents were able to distance themselves from this type of risky behaviour, even though some of the problems they attributed to others had also been described in their own experiences of the difficulties they faced in achieving the targets. Other farmers were identified as the risky others – who posed a threat to farming. Poorly run farms became unsafe places which threatened animal health and farmers' livelihood.

Responsibility for reducing the risk associated with AMR was also ascribed to veterinarians. In the UK all antimicrobials for veterinary use must be prescribed by a veterinarian. The RCVS Code of Professional Conduct states that "The animal or herd must have been seen immediately before prescription or recently enough or often enough for the veterinary surgeon to have personal knowledge of the condition of the animal or current health status of the herd or flock to make a diagnosis and prescribe" (RCVS, 2021). Whilst, all respondents stated that they obtained their prescriptions and antimicrobials from their veterinarians, they indicated that their contact with the veterinarian could be sporadic and may not necessarily occur at the time of illness in the animal:

> *"The vet is not involved generally because if you get an animal sick when I go round them in the morning I'm not going call the vet before I do it (administer antimicrobials)."* Respondent 34 (Sheep farmer)

> *"But sheep farmers don't keep running down the vets, you know, we can sort out our own lambing, we hardly ever go down for a lambing. The vet comes out for a TB test or maybe a calving but they're always too busy to talk to you."* Respondent 15 (Sheep and beef farmer)

Although they reported having little contact with their veterinarians, when identifying and treating infections respondents suggested that veterinarians should shoulder responsibility for helping farmers to achieve antimicrobial reduction targets:

> *"No, the vets are the only ones that are gonna tell you that. And hopefully by doing this you're gonna tell me whether I am or not (over*

using) … the vets gonna monitor it anyhow 'cause you've gotta buy the antimicrobials from the vet, you can't get it any other way." Respondent 2 (Sheep and beef farmer)

"Well, I would've thought the vet would be the best in the know, won't they? They provide us with the antimicrobials so they're in a good position, aren't they, to monitor AMU." Respondent 19 (Beef farmer)

In attributing this responsibility to their veterinarians, respondents appeared to be deflecting responsibility away from themselves alone suggesting that veterinarians should play a significant role in the process. They believed that veterinarians were more knowledgeable about AMU and in control of the situation because antimicrobials must be prescribed by them. However, some farmers noted that antimicrobials could be too easily accessible from the veterinarian, and some were confused about the conflicting information received from veterinarians.

"It's too easy to go to the vet and ask for something and they just give it to you and can be used pretty easily." Respondent 17 (Sheep and beef farmer)

"Sometimes we're slightly conflicting 'cause we wouldn't have always vaccinated lameness, we'd have trimmed and put them in a footrot bath, unless they were really bad and then we would've, but now we're told we've got to use antimicrobials. So it's sort of slightly conflicting information coming out, isn't it?" Respondent 21 (Sheep farmer)

Respondents presented a story of themselves as good farmers who already met the targets set and who would be putting their animals and their reputation at risk if they tried to reduce them further. They portrayed themselves as responsible actors and distanced themselves from accountability for reducing AMU by shifting blame onto poorly run farms and responsibility on to veterinarians. Thus, their responses to risk sought to maintain symbolic boundaries with the farming community particularly in relation to self and others (Ruston, 2009).

9.5. Discussion

This is the first study, to the author's knowledge, to provide insights into the way in which sheep and beef farmers in England and Wales view the feasibility of antimicrobial reduction and the risks posed by AMR. The present study used a qualitative approach and aimed to build on the relationship between risk and habitus to gain an understanding of sheep and beef farmers' decisions and actions relating to reducing AMU. Through gaining this understanding, the study aimed to support successful behaviour change, policy implementation and the reduction in the risk of AMR. The aim was not to quantify opinions and the results do not suggest that every opinion reported is held by every sheep and beef farmer in England and Wales.

However, using this approach the study was able to capture the perceptions, beliefs and motivations that underpin behaviours regarding AMU and the potential for its reduction.

The interpretations of risk presented by Zinn (2008), Zinn (2017) and Lupton (2013) can be used to understand the farmers views of risk around antimicrobial reduction and AMR. Farmers risk judgements around AMU and resistance were shaped by the sociological domains of identity, reflexivity and control (Zinn, 2017). For common diseases such as lameness and pneumonia, use of antimicrobials had become normalised and the treatment and identification of such diseases had become part of the farming lifestyle. As such, their use of antimicrobials for common diseases helped to shape sheep and beef farmers' identity. The risks of reducing their AMU was not deemed acceptable to their identity as a good farmer as this was seen as a detriment to their livestock health and welfare.

Farmers saw AMR as a risk to their identity as it hindered their judgement around identifying and treating common diseases. In an attempt to regain control over the emerging risk of AMR, they carried out a number of practices to prevent disease in their animals. The social relationship between the farmer and their veterinarian complicated AMU practices. Farmers believed that as antimicrobial prescribers, veterinarians had more control over the situation around monitoring AMU.

Farmers largely used in between strategies to make judgements around AMU and resistance. They said they did not have the skills or the resources to make knowledgeable, calculated, rational decisions (Zinn, 2008). Yet, at the same time farmers judgements were not totally irrational. They did not avoid the problem of AMR or rely on fate. Instead, they adopted the precautionary principle and made changes to their practices based on their intuition, tacit knowledge, and emotions.

Farmers in this study drew on their emotional ties to their animals, their habitus and their sense of ontological security – as good farmers - to defend their practices and to blame others for the problem. Their views of problem farms were underpinned by emotions of fear and blame and they were seen as dangerous places (Ruston, 2009, Ruston and Smith, 2013). Thus, their scripts revealed that their habitus - as good farmers – influenced the way they sought to justify action and or inaction in relation to reducing AMU on their farms. They described a risk response that was based on an assemblage of beliefs, ideas, emotion, intuition and logic of practice (Crawshaw and Bunton, 2009) - a risk-emotion assemblage (Lupton, 2013). Their scripts acted as a resource to normalise actions and deal with issues of accountability and reputation management (Enticott, 2011).

Policy makers are increasingly acknowledging that the elimination of all risk presents a major challenge. Focusing on systems that more accurately identify and categorise risks and provide programmes for handling and reducing risks are considered more likely to be effective (Taylor-Gooby and Zinn, 2006). The insights revealed through the scripts in this study have important implications for policy makers who adopt rational approaches to bringing about change. They illustrate how strategies for change based on evidence or on the precautionary principle could be less effective than desired. In particular this study highlights the complexities surrounding the setting of numerical targets for reduction of AMU in the beef and sheep industry. The setting and monitoring of targets is one way in which governments can provide leadership, guidance and strategic direction to achieve a reduction in risks through behaviour change. Targets are expected to motivate people to achieve goals with appropriate milestones, to foster accountability and provide motivation.

Nuti et al. (2017) suggest that governance based on targets is a form of indirect control which requires selecting the appropriate number of indicators to measure the objectives and choosing a rigorous principle to define which indicators should be considered as priority. Targets are extensively used in UK policy particularly in relation to improving health and wellbeing and increasing the efficiency of hospitals. Although targets have met with success evidence suggests that this approach can also be accompanied by unintended negative consequences. For example, in the UK the four hour waiting target for people attending Accident and Emergency services, whilst generally successful has resulted in poorer care for some patients (Anandaciva, 2018). Thus, although targets can change people's behaviour in order to the meet the target they may not choose to do this in the way the target setter intended (Booth, 2010). In addition, Elkan and Robinson (1998) argued that targets focus action on those things that are most easily measured and can foster complacency on the part of providers who have already achieved target levels of performance and defensiveness from those performing badly.

Targets are just one means to achieve progress against a priority, but not all priorities lend themselves to a target. Before deciding on a new national target or whether to have a target at all, policymakers need to consider whether it is the most effective and appropriate means of achieving the desired outcome (Berry et al., 2015). Berry et al. (2015) identified key questions that would need to be addressed to assess the suitability of targets and the data presented in this study provides valuable insights into the potential challenges faced in reducing AMU on sheep and beef farms in the UK. These are discussed below:

Firstly, is there a widely recognised and pressing problem, which requires policy action at a national rather than just local level?

Globally and nationally there is a persuasive need to address the unnecessary use of antimicrobials to ensure responsible use in humans and animals. It was evident through respondents scripts on *AMR as an emerging threat* that the sheep and beef farmers interviewed in this study were aware of the risks associated with AMR stating that it could be catastrophic both for their livelihoods and reputations if they were to develop resistance on their farms. Some feared they may have already observed AMR, and most felt at high risk of experiencing it in the future.

Secondly, is the problem likely to be amenable to action by those who are accountable for the target?

Farmers in their scripts of *experienced, knowledgeable farmers and of risk, defence and othering,* provided a strong rationale for not cutting back on AMU. They believed that they were very low users already - only using them in life and death situations – and that that a reduction in use would increase the mortality in their flocks or herds and in turn, potentially risk their reputation as a good farmer. Given that they reported that they were not able to determine their exact use or calculate a 10% reduction their beliefs were based on subjective views.

Thus while it was evident that the problem of AMR may be amenable to action by the respondents their strong beliefs about the individual animal being a priority and their concerns about being categorised as a bad farmer may result in action that will limited the potential to reduce AMR. Nevertheless, their scripts on *controlling risk and adopting a precautionary principle* suggested that they were signed up to the 'precautionary principle' and that they had adopted alternative measures to reduce the risk of infection on their farms.

However, they did not appear to sign up to the idea that they could be held accountable for the overuse of antimicrobials in farming or adopt the target of reducing their AMU by 10%. Their risk rationales were fluid, relational and contextual (Lupton, 2013). The farmers' cultures were located within specific spaces (their farm) and Lupton (2013) suggests that features of space and place are important in the production and expression of emotional states. Farmers expressed concerns that if they tried to reduce their AMU any further they would put their animals and reputation at risk. These fears were based on emotional ties to their animals on the one hand and their identity as a good farmer on the others.

Experts' attempts to change risk-taking behaviour often fail as they do not engage with peoples' identities, the social rooting of risk-taking and the social power structure. Respondents suggested that farmers who had more intensive systems, or had poorly run farms with high stocking rates were most likely to be the ones who were creating the risk associated with AMR. The act

of other-blaming around the responsibility of AMR by both livestock farmers and veterinarians has recently been highlighted by Golding et al. (2019), where blame was also directed at other farmers with poor antimicrobial practices. Notions of self and risky others can be underpinned by the emotions of fear, distrust, hate, blame.

Thirdly, do the necessary resources to take action already exist or can they be developed?

The RUMA targets for increasing uptake of vaccinations for footrot and abortion have not been maintained at the proposed rate (RUMA, 2019b). Farmers in this study did not feel they had all the necessary resources to take the action needed to meet the antimicrobials reduction targets. In their script on *taking responsibility for the risk* they explained that when they bought in new animals they were not supplied with their health and vaccination history making it difficult to decide on the action to take if the animal became ill. Availability of medicine records could be improved to make it easier for farmers to inspect the medicine history of potential animal purchases and this should improve as plans develop for the UK centralised medicine hub. A livestock information programme is also being developed through an industry-government partnership in order to improve animal traceability (AHDB, 2020a). Electronic medicine books are already available for pig producers with various groups exploring the development of equivalent tools in the cattle and sheep sectors (AHDB Pork, 2020).

The main source of information to support antimicrobial reduction for farmers in this study was the veterinarian. However, respondents suggested that they had limited contact for diagnosing and treating infectious disease, as also indicated in previous studies (Kaler and Green, 2013, Bellet et al., 2015). This implies antimicrobial reduction may reach an impasse if veterinary visits do not become more regular on farms. At the moment, lack of contact with the veterinarian, or infrequent veterinarian visits, is considered normal or acceptable in the sheep and beef sector. Infrequent veterinarian visits may be even seen as a symbol of a good farmer as veterinarians are only used in emergencies or with the emergence of new diseases. Whilst quality assurance schemes in the UK require an annual veterinary visit to the farm with a herd or flock health review (Red Tractor Assurance, 2018), the social conditions around the normal frequency of veterinarian visits needs to change for targets to be effective. Some respondents also felt that antimicrobials were too easily accessible from the veterinarians and antimicrobials could be prescribed without thorough reasoning. This highlights a potential lack of reflexivity around the use of antimicrobials in the sector. If veterinarians do not attempt to question farmers who ask for antimicrobials, then the farmers themselves might not reflect on and examine their own AMU.

Nevertheless, within their script of *risk, defence and othering* they suggested responsibility for achieving a reduction in AMU lay with the veterinarian so there is potential for veterinarians to take a lead in supporting farmers. There is an argument for the increased use of proactive veterinary-led flock or herd health planning that encourages the application of appropriate preventative measures to manage disease risk and use antimicrobials responsibly.

Fourthly, can changes in performance can be adequately measured?

RUMA (2019b) reported that data collection to measure progress remains challenging. Farmers in this study reported not understanding the measurements and were confused about how a reduction of 10% could be measured and achieved. Most respondents believed that the veterinarian should take responsibility for monitoring AMU because they were the ones supplying the medicines. However, at the same time respondents stated that they had minimal contact with their veterinarians for the treatment of their sheep and cattle. Farmers also indicated that they did not have the skills to accurately measure their progress against the numerical targets. To ensure performance is adequately measured it is important that farmers and veterinarians work in partnership, with the farmers supplying farm management data and the veterinarians facilitating the analysis of on-farm AMU. Zinn (2017) suggests that if awareness is lacking or knowledge is inaccurate, education and information strategies might be important for achieving behaviour change.

Fifthly, do the targets align well with what already exists or is planned elsewhere in the system, with minimal negative consequences?

As the farmers in this study believed that they were using as little antimicrobials as possible already, further reductions in antimicrobials were seen as being be detrimental to production and animal health and welfare and therefore associated with negative consequences. For example, lameness is an endemic disease in British sheep flocks and the Farm Animal Welfare Committee set targets to reduce sheep lameness to less than 2% by 2021 (AHDB, 2020b). The five-point plan is a national strategy for achieving this target and one of measures for the control of lameness is to give an antimicrobial injection within three days of the sheep becoming lame. Consequently, farmers may feel that they have to choose between achieving the lameness targets and achieving the antimicrobial targets. Some farmers were minimising their AMU by only treating severely lame sheep with injectable antimicrobials. This indicates that the antimicrobial reduction targets could have a negative impact on animal welfare. Thus, messages need to be clearly delivered to farmers that it is entirely appropriate to treat clinically affected sheep with antimicrobials with emphasis on prevention by rapid treatment and improved biosecurity, which in turn will reduce the lameness level and lead to fewer lame sheep and further reductions in AMU

in the long term. Veterinarians need to ensure that they take the time to explain and provide farmers with context with how using antimicrobials appropriately reduces usage in the long term.

9.5.1. Implications for policy

From the evaluation of the farmers scripts against the five tests for effective targets outlined by Berry et al. (2015), a number of weaknesses in the current targets are evident. Through identifying these weaknesses, we can determine how the targets can be more effective in the future and consequently aid behaviour change around responsible AMU.

Firstly and perhaps most importantly, the majority of sheep and beef farmers have not had their AMU measured officially. Therefore, they do not know how much antimicrobials they are using compared to the targets. A numerical AMU target could be counterproductive if most farmers do not know their numerical use. It is suggested that until there is reliable data collection and robust metrics available there should not be a numerical target set for antimicrobial reduction in the sheep and beef sectors. Targets should first focus on comprehensive collection of antimicrobial consumption data. Other measures of 'responsible' use which are already reported in the RUMA reports could be framed as more important until reliable AMU data is achieved (RUMA, 2019b).

The lack of availability of AMU data also fosters issues with accountability for the targets. As farmers believed that they were low users of antimicrobials, they shifted the responsibility for reducing antimicrobials onto 'others'. From the results of this study it is suggested that the framing of the current targets for the sector should be shifted from *reducing* AMU to *responsible* AMU. At present, the RUMA targets start with an antimicrobial reduction target – such as reducing AMU by 10%. This is then followed by responsible AMU targets – such as increasing vaccine sales to prevent disease (RUMA, 2019b). The targets should instead prioritise the responsible use targets. This will help all farmers feel accountable for the targets.

By emphasising responsible AMU instead of reducing AMU, this will also help to ease the conflicts faced with other recommendations. The focus on reducing AMU could be especially detrimental to sheep lameness control targets. If antimicrobials are to be used responsibly in the sheep sector in particular, the optimal control strategies for lameness need to be highlighted in the report using evidence based reasons, sources and consequences

Finally, the resources available to farmers to support their responsible AMU needs to be developed. As veterinarians are the main source of information for farmers, their means of communication could be developed to provide farmers with better resources. The farmers tended to interpret the sector wide targets in an individualistic manner and placed value on their situational

knowledge when treating animals with antimicrobials. People prefer communication that is tailor-made to them and their values (Redding et al., 2020). Thus, veterinarians could share knowledge and understanding about responsible AMU with farmers based on their values (e.g. animal welfare, reputation) through personal stories. Knowing farmers values and beliefs requires a strong relationship between veterinarians and farmers, however this cannot happen when veterinary visits to the farm are infrequent. Therefore, there is a need to normalise frequent veterinary visits on sheep and beef farms and make infrequent veterinary visits appear less acceptable. Overall, regular veterinarian visits to sheep farmers needs to be embedded in the 'good farmer' ideal.

9.6. Conclusion

This study used qualitative methods to explore beef and sheep farmers' perceptions and their management of the risks associated with potential overuse of antimicrobials on farms. In particular, the study used script theory to examine the potential influence of farmers' beliefs and behaviours on the achievement of national targets to reduce AMU on farms. The beliefs and behaviours, reported by respondents, are of utmost importance for policy makers to consider in terms of achieving national targets set by the RUMA Targets Task Force. Respondents reported not having the technical knowledge and skills needed to measure AMU and resistance, they believed their use of antimicrobials was already low and they were concerned about the potential effect of further reducing use on their business, their animals and their reputations. They deflected accountability and responsibility for dealing with the problem to veterinarians and poorly managed farms. These insights are valuable for policy makers to enable them to set realistic targets, which have research-informed objectives to support farmers and their veterinarians as they aim to make progress in the achievement of the targets. Additionally, the insights may help to form a basis for providing education and training for farmers to mitigate against the risks of AMR developing on their farms. This study demonstrates the value of social science research methods in understanding the factors that influence behaviour change in farming and provides valuable insights for policy makers tasked with achieving behaviour change.

10. Discussion

This final section brings together all the studies that form the thesis. First, a brief reminder of the aims of the thesis are presented in Section 10.1. Then, the key themes that were identified across the thesis are presented in section 10.2. The limitations of the research are addressed and the implications for policy and industry are described in the following sections. Finally, the future directions of the research are considered and final conclusions are drawn.

10.1. Aims of the research

This research used a mixed-methods, multidisciplinary approach to understand how antimicrobials are used on sheep and beef farms in the UK. From the literature review it was clear that there was a lack of information available for the sheep and beef sectors on the quantities of antimicrobials used on farms and the levels of AMR in healthy animals compared with other farming sectors in the UK. Additionally, there was little research into sheep and beef farmers' decision-making around using antimicrobials in their animals, or veterinarians' decision-making when prescribing antimicrobials to these farmers. This led to the development of the following aims:

A. Evaluate AMU recording practices on sheep and beef farms using multiple data sources;
B. Identify patterns in AMR in sheep and beef farms in the UK;
C. Understand veterinary decision-making when prescribing antimicrobials to sheep and beef farmers;
D. Understand sheep and beef farmers' practices and perceptions around AMU.

To achieve the above aims seven studies were designed. Study 1 was designed to fulfil aim A, Study 2 was designed to fulfil aim B and Study 3 was designed to fulfil aim C. The final four studies of this thesis aimed to fulfil aim D. The results of these studies, their limitations, and their implications for future work are discussed below.

10.2. Common themes across the thesis

A multidisciplinary approach was used across the research, exploring epidemiological, microbiological and social science methods to enhance the understanding of AMU on sheep and beef farms in the UK. From the seven studies there were some common themes. First, the importance of recording and interpreting data for AMU and AMR is discussed, before considering the common decision-making constructs identified across the thesis.

10.2.1. Importance of recording and interpreting data

The findings of this research clearly show the key role that recording and interpreting data has on AMU. In particular, the use of electronic recording

was important. For example, sheep farmers who used a computer to record information were significantly more likely to have attitudes to AMU that aligned with current recommendations in Study 5. Additionally, collecting cattle movements digitally was significantly associated with lower AMU on beef farms in Study 4. This shows that encouraging more farmers to use electronic recording may have an impact on lowering AMU. The uptake of electronic recording by farmers is still low (Lima et al., 2018). Furthermore, there may be a specific "type" of farmer that records their information digitally and further research is needed on why there is a link between digital recording and potentially lower AMU. Turner et al. (2017) identified six types or "segments" of Australian sheep and beef farmers, some of which, such as the "proactive manager" and the "benchmarking farmer", made record keeping a higher priority than others. It would be interesting to investigate how AMU fits into these six farmer segments, as this research suggests the hypothesis that farmers who make record keeping a higher priority would have lower – or more responsible – AMU.

Most of the sheep and beef farmers studied in this research recorded information on their AMU. This is not a surprise as it is a legal requirement. However, farmers did not use their recorded information to quantify AMU at the farm level. Similarly, Kaler and Ruston (2019) found that sheep farmers used electronic identification technology to meet legal requirements in identification rather than make use of the electronic data at the flock level. The way AMU data was recorded by farmers meant that that farmers cannot detect herd- or flock- level trends (Escobar and Demeritt, 2017). The findings of this research show the implications of these problems. Farmers were unable to compare their AMU to their past use, or to other farmers use (Study 7). The lack of comparability in AMU data may have led to the perceptions of uniqueness described in Study 6. Likewise, the social norms around AMU, such as the belief that they use a similar amount of antimicrobials to other farms (Studies 4 and 5), may be formed as there is no way of confirming otherwise. The idea that the lack of recording by sheep farmers may contribute to their perceptions of each farm being unique has previously been identified by Kaler and Green (2013). The research in this thesis extends this by showing that the lack of recording and perceived uniqueness meant that farmers did not feel accountable for AMU targets and felt that current recommendations were not aimed at them.

Recording is particularly important for mixed species farms as species-specific AMU cannot be determined by other methods such as veterinary prescribing data or antimicrobial bins. It is already known that sheep farmers find it difficult to keep records (Kaler and Green, 2013, Munoz et al., 2019). The findings in Study 1 support this in that farmers reported that they were able to accurately record antimicrobials administered to cattle, but not to sheep. This was because of the contextual factors relating to the administration of

antimicrobials, where sheep were treated in the field and during busy times. The results from Study 1 also highlight that both sheep and beef farmers struggled to record AMU, with significantly lower AMU recorded in medicine records compared with antimicrobial bins. This is despite farmers saying that their recording of antimicrobial administered to cattle was accurate. Strategies are required to make antimicrobial recording easier for sheep and beef farmers, and until then their AMU from their medicine records should be interpreted with caution.

Study 2 showed that the prevalence of AMR can be different depending on the interpretation method used for disk diffusion testing. The use of human clinical breakpoints may lead to under-reporting or over-reporting of non-susceptible isolates in sheep and beef cattle depending on the antimicrobial under investigation. Different breakpoints can also lead to different interpretations of AMR patterns. The UK does not currently undertake surveillance of AMR in healthy sheep and beef cattle (Bennani et al., 2021). The presence of AMR on sheep and beef farms reported in Study 2 suggests that this surveillance may be useful to keep track of patterns of resistance. Without keeping record of this information, it is impossible to see the impact of AMU on AMR on sheep and beef farms. Whilst much effort has gone into trying to improve AMU data collection in the sheep and beef sectors (RUMA, 2020), there does not seem to be an attempt to coordinate this with AMR data.

10.2.2. Common decision-making constructs across the thesis

Four studies used theory in the methodological design and/or interpretation of results, three of which investigated farmer decision-making. Different theories were applied throughout the studies and sometimes multiple theoretical underpinnings were used as this allowed for a more complete understanding of the underlying decision-making process around AMU. The same concept could be interpreted in multiple ways depending on the theoretical perspective. If entirely psychological theories were used, this would fail to identify the sociological factors that influenced antimicrobial decision-making. Similarly, if an entirely rational theoretical model was used, this neglects the emotional and intuitive processes involved in decision-making.

This research sought to understand the decision-making of farmers and veterinarians around AMU. Decision-making is the cognitive process resulting in the selection of a belief or a course of action among alternative options. From the research, there were six common constructs which influenced farmers' antimicrobial decision-making (Figure 14). These constructs do not occur in a vacuum and are not discrete. Each construct is intertwined with others. They are, however, important when considering behaviour change interventions. As the constructs are interlinked, then selecting one construct

for a behaviour change intervention may simultaneously initiate changes in other constructs. On the other hand, interlinked constructs mean that behaviour change interventions that are targeted to one specific construct may only create small changes in behaviour unless the other constructs are considered. Therefore, knowing how each construct is related is important for successful behaviour change techniques.

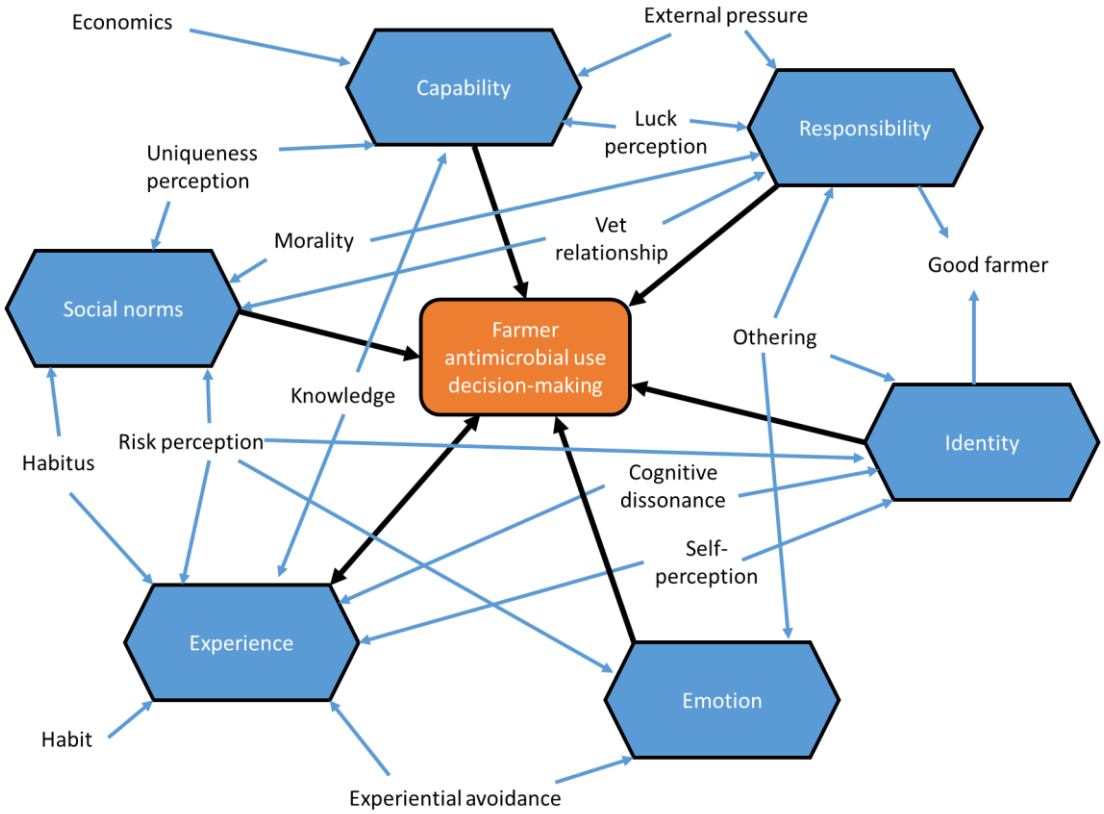


Figure 14: Framework for sheep and beef farmers' AMU decision-making including how the concepts can link together

10.2.2.1. Identity

Much work has been carried out on the "good farming" ideal and what constitutes a good farmer (Burton, 2004, Sutherland and Burton, 2011, Sutherland and Darnhofer, 2012, Shortall et al., 2018, Bellet, 2018). This work was largely based on Bourdieu's theory of practice and the concepts of habitus, capital, and field (Bourdieu, 1990, Bourdieu, 2011). Until now, there was no published research into the ways the good farming identity reflects farmers' AMU.

The good farming identity was a prominent theme across Studies 6 and 7 within this thesis. Farmers' perceptions of risk around antimicrobials were shaped by what farmers understood as symbols of being a good farmer. Good animal welfare was an important symbol of the good farming identity, and Studies 6 and 7 illustrated how this can be a driver for AMU. Reducing AMU at the expense of animal welfare and their reputation was not a risk farmers

were willing to take. As well as being a driver for AMU, the good farming identity could drive antimicrobial stewardship behaviours. Although animal welfare has long been understood as a symbol of good farming (Bellet, 2018), appropriate AMU is perhaps a newer symbol. The good farming ideal can change over time (Sutherland and Darnhofer, 2012), and Study 6 suggests that this is the case for AMU behaviours. For some farmers, antimicrobial stewardship had become a form of cultural capital and a symbol of being a good farmer.

The introduction of AMU targets to the sheep and beef sectors were seen as a threat to farmers' identity as low antimicrobial users. To defend their good farmer identity, farmers distanced themselves from other "bad farmers", who they blamed for high AMU and the emergence of AMR on farms. Golding et al. (2019) also identified that farmers take part in othering to deflect the problem of inappropriate AMU onto others. The research covered in this thesis builds on the work by Golding et al. (2019) by suggesting that farmers took part in othering to protect their own self-identity as a good farmer.

Identity also played a role in farmers' everyday practices on farm. For example, the identification and treatment of common diseases was an ordinary event and part of the daily activities on sheep and beef farms. Previous studies of dairy farmers illustrated that being able to judge animal health status by eye was an important part of farmers' identity (Shortall et al., 2018, Fischer et al., 2019). Study 7 showed that this was also the case for sheep and beef farmers, but also expanded on this by demonstrating that AMR was a challenge to this identity. AMR made assessing health problems more difficult and made farmers' doubt their experience-based skills.

Study 5 addressed sheep farmers' identities from the perspective of self-perception theory (Bem, 1972). Through observing their past behaviours, farmers may make inferences about their own self-identity. Thus, farmers' identities surrounding AMU and AMR may depend on how they use antimicrobials on their farm. A farmer who is engaging in antimicrobial stewardship practices might observe that they are the type of farmer to use antimicrobials responsibly, that it is important to them, and then incorporate this into their identity as a good farmer. This means that there was not just one single identity held by farmers, but multiple, and might explain the conflicting good farmer identities identified in Study 6. Self-perception theory has previously been used to explain why farmers who carried out non-subsidised environmental practices incorporated it into their identity but those who carried out subsidised practices did not (Lokhorst et al., 2011). The freedom to choose whether to enact a behaviour is important in the attribution of a behaviour to a person's identity. This may support the voluntary approach to the reduction and refinement of AMU in agriculture that has taken place in the UK (RUMA, 2020).

10.2.2.2. Experience

A key theme within the research was the role of experience in the use of antimicrobials on sheep and beef farms. Experience is the observation of events or an event that leaves an impression on someone.

The evidence in this research suggests that previous practices may influence farmers' attitudes towards AMU and AMR (Study 5). These previous practices may be directly related to AMU. For example, in Study 6, negative experiences around not using antimicrobials at lambing time led to routine prophylactic AMU as an act of experiential avoidance. Farmers tried to cope with these negative experiences by attempting to avoid or control them. Experiential avoidance has previously been understood as a coping mechanism for people's own illnesses such as irritable bowel disease and anxiety (Newman and Llera, 2011, Trindade et al., 2016). It has also been shown that parents can suffer experiential avoidance if something bad happens to their children (Brown et al., 2015). Study 6 is the first study, to the author's knowledge, that suggests that farmers can suffer experiential avoidance relating to experiences with their animals.

Previous practices may also be indirectly related to AMU. For example, trimming sheep feet was associated with attitudes that did not align with current AMU recommendations in Study 5. These findings suggest there is likely to be several interdependencies between farmer behaviours and attitudes towards behaviours (Hidano et al., 2018).

Sheep and beef farmers' perceptions of risk around AMU and resistance were also influenced by their past experiences. In Study 6, farmers who had previously experienced resistance to anthelmintic were more aware of the financial risks of AMR. Similarly, farmers felt at high risk of developing AMR if they have had previous difficulties in treating diseases (Study 7). These findings show that sheep and beef farmers' developed an awareness around the problems of AMR and excessive AMU due to their own, largely negative, experiences. This perceived threat can lead to changes in behaviour such as reducing prophylactic AMU (Study 6) and adopting disease prevention measures (Study 7). This is similar to findings of dairy farmers' uptake of biosecurity practices, where farmers were motivated to take up biosecurity measures after the disease was already present on the farm (Brennan et al., 2016). For successful antimicrobial stewardship and biosecurity, it is important to try and shape these perceptions of risk around AMU and disease control before these negative experiences occur. This is difficult as farmers see their veterinarians – who are their main source of information for disease control – as firefighters for emergency situations rather than experts in disease prevention (Kaler and Green, 2013, Ruston et al., 2016).

Farmers' experiences shaped the way they made everyday decisions around AMU on farms. The identification and treatment of common diseases was

learned through farmers' upbringing on farms and embedded in the cultural knowledge of farming. In line with previous research (McDougall et al., 2017, Ekakoro et al., 2019), farmers relied on their previous experience and knowledge to assess whether antimicrobial treatments were required. Farmers placed value on their experiential expertise over their veterinarians' clinical and scientific expertise, only choosing to ask for their veterinarians' expertise when their own experiential expertise could not solve a problem. Farmers have what is known as "knowing otherwise" expertise, tacit knowledge that can only be obtained through going through an experience (Walklate and Mythen, 2011, Baillergeau and Duyvendak, 2016). This may be why farmers in this research have sometimes dismissed their veterinarians' advice. Veterinarians do not have this "knowing otherwise" expertise as they do not experience what farmers live through.

When a behaviour is regularly repeated and the experience is rewarding, it can become automatic or habitual and other alternative behaviours become less accessible in memory (Gardner, 2015). Therefore, decision-making may sometimes be an automatic process. This may be the case for farmers as many of the practices they carry out are traditional and do not change over the years. An example in sheep farming is in the treatment and control of lameness, where foot trimming persists as a common management practice despite best practice recommendations advising against it (Best et al., 2020, Green et al., 2020). There has been very little evidence that habit may influence farmers' antimicrobial decision-making. Visschers et al. (2014) suggested that the habit of relying on veterinarians' decisions relating to AMU in pigs was associated with lower AMU by farmers, but the study does not show how relying on veterinarians' decisions is actually a habitual behaviour (i.e. a repeated behaviour over time). Study 5 provides some evidence of the influence of habit on farmers' decision-making. It shows that traditional practices, such as foot trimming sheep and anthelmintic practices were associated with farmers having an attitudinal profile that did not align with current AMU recommendations. Additionally, veterinarians were more likely to prescribe antimicrobials to farmers who use the antimicrobial at the same time every year (Study 3). This echoes what is seen in human medicine, where habitual practices were followed in hospitals even though they did not correlate with best practice (Broom et al., 2014). Habitual behaviours are triggered by contextual cues (Gardner, 2015). For farmers the contextual cues could be the time of lambing (Study 6) or a common symptom such as a high temperature (Study 7). Because habitual behaviours are automatic, they are difficult to change; however, the Studies 6 and 7 offer some examples of how farmers have done so. New experiences can disrupt old habits and create changes in behaviour. For example, experiencing signs of AMR on their farm prompted farmers to take action against the threat of AMR. Therefore, it may be successful to target behaviour change in farmers when they are

experiencing something new, such as a new emerging disease, a new breed of cattle on the farm, or a new barn being built. This is called the habit discontinuity hypothesis, where major life changes provide a window of opportunity for behaviour change because people are more open to change during these times (Verplanken and Roy, 2016).

Veterinarians may also prescribe antimicrobials to sheep and beef farmers out of habit (Study 3). Previous research suggests that veterinarians rely on their previous experience and may be reluctant to change their treatment practices (Gibbons et al., 2013, Coyne et al., 2018), but it is unknown how habits are formed at the veterinary practice. Work in human medicine indicates that habitus and peer practice norms have a role to play in the formation of habitual prescribing practices at the hospital level (Broom et al., 2014). Habit formation at the veterinary practices warrants further investigation.

10.2.2.3. Social norms

Social norms can be defined as "unwritten codes of conduct that are socially negotiated and understood through social interaction" (Chung and Rimal, 2016). There are two different types of social norm. Descriptive norms refer to the perceptions about how other people behave and injunctive norms refer to perceptions of what is approved or disapproved by others. Social norms can be at the individual level or at the societal level.

The research across this project shows that social norms may lead to inappropriate AMU behaviours. Study 5 indicated that the prophylactic use of antimicrobials in neonatal lambs was a relatively common practice on sheep farms in the UK. From this, Study 6 showed that the use of oral antimicrobials had become normalised on sheep farms, and so oral AMU did not carry the same stigma as other forms of antimicrobial administration. In fact, farmers may think that using prophylactic antimicrobials was acceptable even if they did not carry out this practice themselves (Studies 4 and 5). Furthermore, the study investigating veterinary prescribing behaviour revealed that the prescribing of antimicrobials for the prevention of watery mouth may still be a generally accepted practice by veterinarians. This shows how the prophylactic use of antimicrobials in lambs has developed into a societal norm. It has become part of the "rules of the game" in the sheep farming field. This links with the construct of identity as those who identify as being part of the sheep farming field will comply with the field's social norms. Similar findings have been identified in a study of dairy farmers' treatment of mastitis, in which farmers extended the duration of antimicrobial treatments to comply with social norms (Swinkels et al., 2015).

As highlighted in Section 10.2.1, the absence of utilising data in the sheep and beef sectors may contribute to the presence of social norms. For example, in Study 6 farmers thought that each farm was unique and used this justification

to avoid social disapproval around AMU. On the other hand, many farmers thought that they used a similar quantity of antimicrobials as other farms. Thus, a balance must be struck where farms were unique enough to have differing needs for AMU, yet similar enough to not deviate from social norms. This perception that farms are unique is not exclusive to sheep and beef farming or farmers. In dairy farming, veterinarians adapt protocols for bovine tuberculosis testing based on local universalities (Enticott, 2012). That is, the relations between veterinarians, other veterinarians, farmers, cattle, machinery, bodily parts, and sensations. Similarly, the uniqueness of farms perceived by sheep and cattle farmers was not just the unique farm characteristics but its relation to the farmer, veterinarian, animals, weather, feelings, and other actors.

Farmers' decision-making is therefore formed by their social environment, or habitus, which shapes what is considered normal or what is unreasonable. Another example is the low contact with veterinarians on sheep and beef farms. Although previous studies suggest that veterinarians are a key source of information for farmers' AMU (Jones et al., 2015, Swinkels et al., 2015, Etienne et al., 2017, McDougall et al., 2017, Fischer et al., 2019), the results of this research suggest that this influence may not always be large enough to make significant changes to sheep and beef farmers' AMU practices. Sheep and beef farmers rarely called their veterinarian out to visit the farm because veterinarians were only used for problems farmers could not deal with themselves. This has also been shown in British sheep farmers (Kaler and Green, 2013) and Swedish dairy farmers (Fischer et al., 2019). Therefore, high veterinary contact may not appear acceptable within the sheep and beef farming fields as this could indicate that they were farms with disease problems. Low veterinary contact was seen as a positive indicator of a good farm. This has parallels in human medicine, where cultural values, such as ideas about the physician's role in the physician-patient relationship and self-efficacy, affect the patients' demands for antimicrobials (Wagner et al., 2020). Therefore, farmers' AMU may be shaped by cultural norms of the farmer-veterinarian relationship. A loss of social prestige around rare veterinary visits is required if regular veterinary visits are to become a social norm (Hernando-Amado et al., 2020).

Social norms that sheep and beef farmers follow are not just governed by sheep and beef farmers as a group. Other actors, such as veterinarians, industry, the media, and members of the public, may also govern how sheep and beef farmers ought (not) to act. Such actors appear to drive social norms around responsible AMU on farms. For example, in Study 6, farmers who did not use antimicrobials prophylactically in their lambs were influenced by consumer perceptions, veterinarian advice, and legislation. Additionally, in both Studies 4 and 5, many farmers agreed that society thought that farmers used too much antimicrobials. Therefore, farmers may make decisions to seek

approval from people other than farmers. This conflicts with previous research that suggested that society hardly influenced German and Dutch farmers' antimicrobial treatment decisions and farmers' rejected society's social norms (Swinkels et al., 2015). The difference might be because of cultural differences between the UK and Germany and the Netherlands, or it might be because of changes in the perceptions of antimicrobials or farmers' relationships with consumers in the past five years. Study 6 also presented a group of farmers who were resistant to social pressures from their veterinarians or other members of society. A study of Danish pig farmers showed that farmers' processed social stigmatisation in different ways and may offer some explanations as to why some farmers did not comply with societal social norms in the research in this thesis (Fynbo and Jensen, 2018). The wider group norms identified in this research probably reflect that AMR is a global health concern that affects every human and animal in the world (Hernando-Amado et al., 2020). Although the studies show that these wider social norms exist in Britain, ideally the social norms need to be present at a global level for AMR to be tackled successfully.

10.2.2.4. Capability

The construct of capability refers to how capable a person is, or how capable the person believes they are, to carry out a behaviour. Both internal and external factors can affect a person's capability.

Across the research in the thesis, farmers have shown that they believed they did not have the capability to contribute to antimicrobial stewardship. In Study 4, only half of beef farmers thought they had the support they needed to reduce their AMU, and less than half expected to reduce their AMU in the next three years. The qualitative Study 7 and mixed-methods Study 6 allowed for further exploration into this perception of capability. They revealed that external factors prevented farmers from having the ability to control diseases. Lambing times were governed by market demand, meaning lambs were born in unfavourable conditions. Similarly the low incomes of sheep and beef farmers left little room for investment in disease prevention strategies. Hinchliffe et al. (2018) name this relation between cash flow and capital investment as "farming on the margins". Their work investigated the shrimp farming industry in Bangladesh. The decision-making research across the thesis shows how even farmers in higher income countries, such as those in the UK, face "farming on the margins". Farmers believed that they were not capable of reducing their antimicrobials any further without negative effects on animal welfare. Thus, the unequal power balance between farmers and the market meant that farmers no longer felt in control of preventing diseases on farm.

These external factors that affect capability are particularly important because they represent a barrier between knowledge and the

implementation of recommended practices. For example, even though farmers knew that optimal colostrum management and a clean environment were effective strategies for the prevention of neonatal disease, farmers said that they were unable to enact these strategies. Fischer et al. (2019) also reported that economic and labour constraints were the reasons for dairy farmers' lack of uptake of AMU recommendations, rather than lack of knowledge. Yet, Studies 4, 6 and 7 revealed aspects of antimicrobials where farmers' knowledge was lacking. Some farmers were not aware which medicines were or were not antimicrobials, others were using antimicrobials for diseases they would be ineffective against, and some farmers did not know how to interpret their AMU. Similar knowledge gaps have been highlighted by Higham et al. (2018), where dairy farmers were not aware of which footbaths contained antimicrobials and many farmers could not accurately describe what AMR was. It is important to improve farmers' knowledge around AMU and AMR as there is evidence that higher levels of knowledge are associated with lower AMU (Kramer et al., 2017).

Farmers often said that their AMU was as low as possible and they were not capable of reducing their AMU further without having disease problems. Previous studies have demonstrated that the lack of recording by sheep farmers in particular means that veterinarians are unable to offer valuable preventative services to sheep farmers (Kaler and Green, 2013, Bellet et al., 2015). Similarly, many sheep and beef farmers did not accurately record their AMU in Study 1. Thus, lack of recording by farmers may negatively impact veterinarians' abilities to provide disease prevention advice, which in turn impacts farmers' abilities to prevent diseases and reduce their AMU.

Trust is required when there is a lack of knowledge or control over a situation (Zinn, 2016). Farmers put trust in their veterinarian to monitor their AMU and ensure they were using antimicrobials appropriately. The most important factor that influenced veterinarians' prescribing decisions was confidence in the farmers' judgements of disease. As veterinarians do not often visit sheep and beef farms and may prescribe over-the-counter, they must place trust in farmers' description of disease to make sure they are reaching the appropriate prescribing decisions. At the same time, farmers do not have the equivalent scientific and clinical knowledge around antimicrobial treatments as their veterinarian and must trust their veterinarians' treatment decisions (Study 7). Work on biosecurity also show that whilst farmers have skills in visually assessing animals for illness, a veterinarians skill is needed when symptoms are not visible (Shortall et al., 2018). Likewise, AMR was an invisible threat on sheep and beef farms which required the skill of a veterinarian to determine. There is therefore an essential trust relationship between farmers and their veterinarian. For such a trusting relationship to develop, there needs to be positive experiences where trustworthiness is proven (Zinn, 2016). This may be why veterinarians were more likely to

prescribe antimicrobials to long-term clients (Study 3). In Study 6, farmers were worried that restrictions to how antimicrobials were used on farms could prevent this development of trust between farmers and veterinarians because it would not allow farmers to demonstrate their trustworthiness. On the other hand, a lack of trust in their veterinarian may be one reason why farmers' did not always listen to their veterinarians' advice. Studies of dairy farmers have identified that lack of trust in the veterinarian or their advice was one of the main reasons for the non-adherence of preventative disease measures (Svensson et al., 2018, Svensson et al., 2019).

Internal factors also impact farmers' perceived capability to contribute to antimicrobial stewardship. Farmers sometimes put disease events down to fate or luck, and hence the event was out of the farmers' control. This means that farmers were less likely to take up practices to try and prevent diseases, as disease events were predetermined for each farm. Enticott (2008) also identified the perception of luck to be a barrier towards the uptake of bovine tuberculosis control measures on dairy farms. Study 6 of this thesis further develops the problem by identifying that these perceptions of luck and fate facilitated this perception of "uniqueness" on farms. Even if farmers were equally skilled, the uniqueness of each farm meant that every farm did not have the same level of control over preventing diseases.

10.2.2.5. Responsibility

Responsibility is the belief that the person's actions could prevent or provoke consequences. Farmers' perception of responsibility had several influences on their decision-making around AMU. First, some farmers felt a moral responsibility to ensure appropriate AMU. They had the power to control their own AMU and therefore were responsible for the possible consequences of AMR and damage to the reputation of sheep and beef farmers. This moral responsibility was shaped by social norms and the written and unwritten codes of society. Therefore, farmers' habitus and their sense of good farming identity were important in their perception of moral responsibility for AMU. Previous studies showed that farmers felt they had responsibilities for land stewardship as a response to societal environmental concerns (Saunders, 2016, Mills et al., 2017). Similarly, the studies across this thesis show that responsibility for antimicrobial stewardship can come from external sources of pressure. For example, in Study 4 and Study 5, many farmers agreed that society thought that farmers used too much antimicrobials and that the media paints a negative view of their AMU. Moreover, in Study 6 some farmers thought that responsible AMU was the right thing to do in the eyes of society; they were following an injunctive norm.

In contrast, Study 6 also suggests that some farmers believed that presence of disease, and therefore AMU, was down to luck. In these cases it was not

appropriate to hold someone morally responsible for their AMU and the possible consequences. Luck can be understood as in contrast to control, and someone who is not in control of their actions cannot be morally accountable for them (Nelkin, 2019). In a study of English dairy farmers, expressions of luck and lack of control meant that farmers could avoid blaming themselves for a bovine tuberculosis breakdown (Enticott and Vanclay, 2011). This study was one of the first to use script theory to understand animal health risks and the author's suggested that greater knowledge of rural scripts may enhance the understanding of rural communities (Vanclay and Enticott, 2011). Thus, scripts were used in Study 7 to understand sheep and beef farmers' responsibilities around AMU. Farmers took responsibility for the risks of AMU by adopting the precautionary principle and making changes to biosecurity and practices to manage animal health. However, the study also showed that farmers pushed responsibility for monitoring AMU to their veterinarian. This was different to the scripts of controlling bovine tuberculosis, where blame was put on the government and scientists who they believed had a lack of knowledge on bovine tuberculosis transmission (Enticott and Vanclay, 2011). Farmers thought that veterinarians were the ones who were ultimately in control of antimicrobials because antimicrobials must be prescribed by veterinarians who they saw as more knowledgeable around the science of antimicrobials. Although farmers put responsibility on veterinarians for monitoring AMU, it was evident from the results of Studies 4 and 5 that many farmers were not having conversations around AMU or AMR with their veterinarian. Veterinarians, therefore, hold a tacit responsibility for AMU on farms.

Farmers have previously been shown to place the blame and responsibility for rising AMR on other veterinarians and farmers (Coyne et al., 2018, Golding et al., 2019). The research across this thesis extends this by providing evidence that farmers also put responsibility onto bad farmers for other consequences relating to high AMU and AMR. For example, in Study 6 farmers blamed other farmers who use prophylactic antimicrobials for the negative views of consumers around AMU in agriculture. Study 7 showed that farmers shifted blame for reaching AMU targets onto poorly run farms. This shifting of the blame meant that farmers no longer felt accountable for the AMU targets and were able to justify their own AMU. This demonstrates how other-blaming can have a negative impact on the achievement of AMU targets if they are not framed appropriately.

10.2.2.6. Emotion

Farmers' decision-making was not entirely rational and "in-between" strategies were used. An integral part of farmers' decision-making in Studies 6 and 7 was their perception of risk around antimicrobials. Emotion is often important in decision-making, especially when the decisions come with risk and uncertainty (Zinn, 2016). From a sociological perspective, emotions are

social constructions based on shared understandings and previous experiences (Lupton, 2013). Judgements about what is considered a risk is dependent on the social and cultural context, personal experience, and emotions. Farmers must judge whether AMU or AMR is a threat or a danger to them and their animals, with emotions contributing substantially to these judgements.

The effects of emotion on farmers' decision-making has rarely been researched. Some examples include the association between sheep farmers' emotions and the uptake of best practices for the control of footrot (O'Kane et al., 2017), the role of emotions dairy farmers' decisions to adopt innovations (Rieple and Snijders, 2018), and farmers' emotional responses to influenza outbreaks (Hernández-Jover et al., 2012, Cui et al., 2019). Hidano et al. (2019) hypothesised that the emotional impacts of stressful events on farmers may determine the behavioural consequences or coping strategies that are linked to these events. Indeed, Study 7 showed how sheep and beef farmers feared disease in their animals and drew on their emotional ties with their animals to justify their AMU.

Lambing time could be thought of as a stressful event for sheep farmers. In Study 6, feelings of fear and regret shaped farmers decisions to use antimicrobials in their lambs. Their emotions were based on previous experiences which resulted in death and illness in their animals. The social constructions of what constitutes a good farmer meant that farmers felt guilt and self-blame when animals died. They used antimicrobials in an attempt to avoid previous negative experiences and maintain their identity as a good farmer. Emotions of fear may also shape farmers decisions to use antimicrobials more appropriately. Previous experiences of anthelmintic resistance and being unable to treat disease developed farmers' understanding of the risks of AMR. As a consequence of these two opposing risks: AMU as a risk and lack of AMU as a risk, Study 6 showed that the discourse of discussing AMU was loaded with emotion. Debates centred on the need to use antimicrobials at lambing time, with those who only used therapeutic antimicrobials accusing others of being dirty or lazy and those who did use prophylactic antimicrobials accusing others of being condescending.

The othering that farmers take part in was also fuelled by emotions. Othering occurred because of a perceived threat to the farmers' self-identity and a feeling of self-defence. Therefore, farmers' emotions of fear and blame underpinned their views on "bad farms". Other "bad farms" were seen as risky places and evoked a sense of being "at-risk", fear, and anxiety (Ruston, 2009). They distanced themselves from "bad farms" and viewed their own farms as safe spaces, evoking feelings of security and pride. "Bad farms" were

understood as different and did not follow the symbolic boundaries of being a good farmer and were therefore viewed as threatening.

In human medicine, addressing the emotional factors that are likely to influence antimicrobial prescribing has been advocated (Donisi et al., 2019). Doctors may prescribe against the guidelines because of the high pressures and fears of losing patients (Broom et al., 2016, Broom et al., 2017), which is similar to the anticipated regret that farmers felt in Study 6. There has been very little evidence of the role of emotions in farmers' AMU decision-making prior to this research. From these findings, it is also recommended that the emotional factors that influence farmers' AMU need to be addressed if behaviour change interventions are to be successful. Golding et al. (2019) highlighted that veterinarians may prescribe antimicrobials as a way to manage farmers' emotions. In future work, it may be beneficial to investigate the role of emotions on veterinarians' prescribing behaviours and how this links with farmers' emotions.

10.3. Limitations of the research

The limitations of each study within this thesis are specifically addressed within their respective chapters. This section provides a discussion on the more general limitations of the research.

10.3.1. Validity and representativeness

The longitudinal study required a smaller sample of farms to take into account the logistical considerations on the researcher. The exclusion criteria for the number of animals of the farm meant that the farms that were part of the study were on average larger than the average sheep or beef farm in England and Wales (DEFRA, 2021). They were also mainly located in the West of England and Wales. However, the study still included a wide variety of farm sizes and the West of England and Wales is where sheep and cattle farms are most densely populated (APHA, 2018a, APHA, 2018b). The sample would be more representative if some more farms in Northern England were included.

Study 2 investigated presumptive *E. coli* isolates and not testing these isolates further to confirm their species may have affected the validity of the results. The TBX agar used in this study is used as standard for the detection and enumeration of *E. coli* in food and water without further confirmation, but research suggests that this technique can sometimes result in false positives (Vergine et al., 2017).

For the sheep and beef survey studies the target populations were 830 and 550 sheep and beef farmers that supplied to two abattoirs, respectively. The response rate was relatively high at 56% and 31% for the sheep and beef surveys, respectively. The characteristics of the farmers that did not respond to the surveys was not known and so the representativeness of the sample is difficult to determine. Again, these farmers that took part in the surveys had a

higher average number of livestock than the average across England and Wales (DEFRA, 2021). It may be that the original source population had larger farms than the general sheep and beef farming population, or that farmers who had larger farms were more willing to participate in research. Although most of the surveys were filled out online, farmers were also given the option of a paper-based survey and therefore the use of online surveys should not affect the representativeness of the sample.

Validity of the farmer surveys (Studies 4 and 5) was improved by initially piloting the surveys on a small sample of farmers. This meant that any ambiguous wording was identified and changed before the roll out of the surveys. Although the antimicrobial rating statements used to understand farmers' attitudes towards AMU and AMR were based on those previously used in published studies, these statements have not been validated (Jones et al., 2015, Etienne et al., 2017). It is possible that they may not measure what they were intended to measure, especially if farmers did not understand what an antimicrobial was.

The veterinarian survey (Study 3) had a practice response rate of 24%, where 813 veterinarian practices were sent the survey and 306 responses were received from 199 practices. It is difficult to determine the representativeness of the sample as the number and characteristics of veterinarians who work with sheep and beef cattle in the UK is unknown. The study sample could be compared to the demographics of the veterinarians who respond to the RCVS survey of the profession (Institute for Employment Studies, 2020). However, the survey of the profession reports demographics for all veterinarians and not just farm animal veterinarians whose demographics may be different. Validity of the survey was improved by piloting the survey with a sample of farm veterinarians. The factorial survey design also increased internal validity because of the experimental manipulation of vignettes which were randomly allocated to respondents. The ten item personality inventory, which was used in the survey to measure respondents' personality has been validated, but it is suggested that it should only be used “when time and space are in short supply and when only an extremely short measure of the Big Five will do” (Gosling et al., 2003, Ehrhart et al., 2009). Considering that measuring personality was not the main aim of the survey and that the factorial survey design may be cognitively challenging for respondents, the ten item personality inventory was judged as appropriate for this survey. The use of the vignette variables to measure the constructs such as habit, time pressure, and confidence in the farmer were not validated and it is possible that they may not measure what they were intended to measure.

For the qualitative studies, small sample sizes were not a limitation and were required for the in-depth examination of responses. The farmers for Study 7 represented a mixture of farm types and sizes which were mainly from areas

where sheep and cattle are densely populated (APHA, 2018a, APHA, 2018b). It was not possible to obtain demographic data for the study population of Study 6 because the data was collected from forum posts and the researcher took part in an unobtrusive method of data collection. The samples sizes for the qualitative methods were determined by data saturation. Data saturation can be defined in many ways, but for these studies it was achieved when no new codes were derived from the data and therefore no new themes could be developed (Saunders et al., 2018).

10.3.2. Bias

The majority of studies within this thesis - with the exception of Study 1 - were cross-sectional. As information was collected at a single time point, it is not possible to infer causality between risk factors and the outcome. Additionally, changes in behaviours and attitudes over time cannot be assessed and this may be a source of bias in the studies where modelling takes place in particular (Hidano et al., 2018). Rather, the cross-sectional studies indicate that an association exists between risk factors and the outcome.

As AMU and AMR may be considered a sensitive topic, this can lead to social desirability bias (De Vaus, 2013). Although efforts were put in place to minimise social desirability bias, especially in the designs of Studies 3 and 6, the farmer and veterinarian respondents may still give a socially desirable response rather than a true response. This might particularly be the case for face-to-face interviews (De Vaus, 2013), and also the farmer surveys as they were distributed by the retailer and abattoir staff. The study samples within this research may also be affected by selection bias as it is likely that those taking part were more interested in AMU and AMR. Therefore, responses may be more in line with current recommendations and less likely to be socially undesirable. Study 6 was less likely to be affected by selection bias in this way as farmers were studied in a naturalistic decision-making setting.

Finally, the surveys may be subject to recall errors as farmers had to retrospectively indicate practices that took place in the past year. Respondents may have an inaccurate or incomplete recollection of events which can lead to recall bias. A survey with only a small period of recall might reduce recall bias but would provide very little information as farm management practices tend to be seasonal. Thus there is a trade-off between the information gained from the surveys and the potential for recall bias. Frequent and typical events tend to be less accurately self-reported than unusual and rare events (Khare and Vedel, 2019). Farmers who use more antimicrobials may have less accurate self-reports of their AMU compared with farmers who use very few antimicrobials. There might also be some recall bias due to forward telescoping or reverse telescoping, where respondents remember an event occurring within the study period when it

actually occurred before or after the period under study, respectively (Khare and Vedel, 2019). Memory aids, such as medicine books, could help to enhance the recall around AMU. This relies on the farmer being motivated to go back through their medicine records.

10.4. Policy and industry implications and impact

10.4.1. Impact in forming new antimicrobial use targets

The investigation into AMU on sheep and beef farms in the UK was a new and much needed area of research. Consequently, the results of this research have had a large impact on the sheep and beef sectors. First, the findings of Study 7, which investigated farmers' views on the sheep and beef AMU targets at the time, were published in a peer reviewed journal (Doidge et al., 2020c). The findings of the paper with critique of the RUMA targets led to a meeting with members of RUMA, where the findings were presented and discussed. This encouraged a move away from numerical targets and a focus on data collection. The newest RUMA report no longer uses numerical reduction targets for the sheep and beef industry and instead aims to capture AMU data from around 10% of sheep and beef farms by 2024 (RUMA, 2020). Two other studies from this research were also published in peer reviewed journals and used in the RUMA report. Findings from Study 4 were used in the report to provide evidence of pneumonia being the main problem for AMU on beef farms (Doidge et al., 2020b). This paper is particularly useful for industry because it provides some of the first published insights into how antimicrobials are used on beef farms in England and Wales, an area where evidence is markedly lacking. The findings from Study 3 were used to emphasise the role of veterinarians on sheep and beef farms (Doidge et al., 2019).

10.4.2. Implications for knowledge exchange

The research highlights some standout areas for knowledge exchange between farmers and veterinarians. First, although farmers have experience and their own situated knowledge around the antimicrobial treatment of common diseases, they might not make the most appropriate decisions. Some examples in the research include the use of antimicrobials for uncomplicated diarrhoea in calves (Study 4) and the use of spectinomycin for the treatment or prevention of joint ill in neonatal lambs (Study 6). As these are common diseases, farmers are unlikely to ask their veterinarian for advice. Veterinarians need to ensure that their clients know what antimicrobial should be used for what disease, and in which cases should antimicrobials not be used at all. This should happen without relying on farmers to prompt for this advice. On a similar note, Study 4 indicated that many farmers do not know what a CIA is, and some farmers do not understand what an antimicrobial is, with particular confusion around vaccines. This has important implications as information campaigns

encouraging vaccine uptake and discouraging blanket AMU will be unclear for those who are confused about the difference between vaccines and antimicrobials.

One potential way that knowledge could be shared with farmers is using an identity-based motivation intervention technique (Oyserman et al., 2002). This type of intervention based on social-psychological theory and is usually used in schools to improve students' attainment. It could also be useful for farmers because it targets identity, which the research across this thesis showed was an important decision-making factor for antimicrobial use. Farmers would meet as a group and would choose among descriptions and images portraying farmers who are successful in reducing antimicrobial use in varying ways. Then the aim would be for farmers to create a timeline and identify any possible choices or problems that might occur in the future that could impact their progress. This intervention would facilitate discussion of antimicrobial use between farmers which this research shows is currently lacking.

10.4.3. Implications for communication strategies

The way in which information is communicated to farmers may make information campaigns more or less effective. The research suggests that farmers prefer information that is tailor-made to them. Therefore, mass media campaigns may not reach the intended audience. If mass media campaigns are used, then it is important to think about the way the messages are framed as farmers may think that the message does not apply to them. This research shows that communication strategies need to consider how the intended messages reflect farmers' identity. Veterinarians may be best placed to give individual advice on AMU and AMR to farmers because of their scientific and clinical expertise and relationship with clients. This means veterinarians will need to improve their prescribing practices, such as reducing prescribing for the prevention of watery mouth, or prescribing out of habit. Another alternative source of advice is other farmers who have successfully changed their AMU behaviours whilst still being productive and maintaining animal welfare. Farmers may value this because these successful farmers will have "knowing otherwise" expertise and will have lived through similar experiences.

10.4.4. Implications for existing benchmarking strategies

The research shows that it is important to consider the potential side effects of implementing antimicrobial reduction targets. In particular, consideration of the five factors used in the construction of NHS targets was a useful approach to understand how targets can be implemented effectively in the farming sector (Berry et al., 2015). Other countries who plan to set targets for AMU may benefit from using this approach to try and avoid negative consequences of target-setting.

Countries such as the Netherlands and Denmark already benchmark farmers against a target for AMU (Sanders et al., 2020). For these countries it is essential to consider the source and quality of the AMU data, especially if farmers or veterinarians were to be penalised for not reaching targets. The following section describes how the quality of farmer-inputted AMU data can be improved.

10.4.5. Implications for the new antimicrobial recording system

The research draws attention to some situations in the current way farmers' record AMU information which may cause problems for the livestock recording system that is under development (AHDB, 2020a). First, group treatments are often recorded and therefore there should be an option to include group treatments on the livestock information system. Second, sometimes mixed species farmers do not indicate which species the antimicrobials were used in. This should be overcome if ear tag identification is a required field on the new livestock information system. For group treatments where this might not be possible, indication of species should be a mandatory field. Finally, treatments for neonatal lambs were often not recorded by farmers. The livestock information system may need to add extra prompts to ensure they receive information on treatments to neonatal lambs. It is also important to note that medicine recording may not reflect actual AMU. This could perhaps be improved if industry encouraged and provided training in the use of electronic identification tools as many of the barriers towards antimicrobial recording was contextual problems in the field. Electronic identification tools allow for the easy identification of animals and recording of information. Study 6 indicated that supermarkets have a powerful influence on farmers' decisions and therefore encouragement in the use of EID tools and medicine hub may improve uptake by farmers.

Study 1 showed that the information that farmers' recorded was varied, which can make it difficult to make comparisons between farms. The use of a medicines hub will help to standardise the information that is recorded for antimicrobial use. However, the developers would have to consider how antimicrobial use data can be transferred from other recording software that farmers are currently using because the software might not be compatible. As the research showed that farmers' often have little time for data recording, it is important that farmers do not have to duplicate their data entry.

10.4.6. Implications for AMR surveillance in sheep and beef cattle

In Section 10.2.1, it was suggested that attempts to monitor AMU in the sheep and beef sectors should be coordinated with the collection of AMR data. Indeed, the strengthening of laboratory surveillance of AMR in animals was one of the key aims of the UK's five-year AMR strategy (UK Government, 2019). The findings of Study 2 provided some important implications for the surveillance of AMR in farm animals. It suggested that the NRI method could

be suitable to define livestock-specific cut-off values to determine antimicrobial susceptibility of isolates of animal origin. This is because (1) human clinical breakpoints were not appropriate for sheep and beef isolates as they cut through the normal distribution of zone diameters; (2) the NRI method allows for calibration of results across multiple laboratories; and (3) the NRI method is a transparent method for calculating cut-off values. Therefore, national surveillance of AMR in farm animals should work towards using livestock-specific cut-off values, for which the calculations should be transparent so that comparisons can be made from different studies and laboratories.

10.5. Future directions

As the research within this project has been mainly cross-sectional, future research should centre on longitudinal designs to be able to determine the nature of the associations between AMU and AMR over time. Studies 1 and 2 provide important information on how AMR and AMU can be measured on sheep and beef farms. These methods could be applied to the monitoring of a more representative sample of sheep and beef farms over several years. The geographical area could be widened to include farms in Scotland and Northern Ireland, as well as England and Wales. A longitudinal study over multiple years would aid the development of a baseline whilst allowing for changes due to seasonality and ages of the animals on farms. After a baseline is developed, then changes in AMU and AMR can be followed over a long period of time. This will help to provide robust evidence on the associations between AMU and AMR on farms.

The results from the decision-making studies within this project can also be used to develop a longitudinal study. For example, Study 5 investigated the associations between farmers' attitudinal profiles and their past farm practices. A longitudinal study could build on this by determining the direction of the associations between attitudes and behaviours. The findings would help to understand whether cognitive dissonance or self-perception theory are significant in the formation farmers' antimicrobial use attitudes, as hypothesised in Study 5. Understanding the direction of influence between antimicrobial attitudes and behaviours is important for the design of intervention studies to establish whether the target should be attitudes towards the behaviour or the behaviour itself.

Antimicrobial behaviour intervention studies are common in human medicine, but rare in veterinary medicine (Wilkinson et al., 2019, Gozdzielewska et al., 2020). The constructs for farmers' antimicrobial decision-making identified within this project may be useful in the design of antimicrobial stewardship interventions on farms, as they provide an understanding of the influences of behaviour and the contexts in which they occur. The constructs can be used to determine the most appropriate

intervention type by applying the behaviour change wheel (Michie et al., 2011). For example, farmers' antimicrobial decision-making may be influenced by their emotional responses. Therefore, persuasion style interventions which aim to stimulate positive or negative feelings through communications may be effective (Michie et al., 2011). Social norms were also identified as an influence of farmers' antimicrobial decision-making. Social norm feedback interventions have successfully been used to attempt to change human doctors' prescribing behaviour (Bradley et al., 2019, Ratajczak et al., 2019). Similar feedback style interventions could be used for farmers' behaviour change. For example, to reduce prophylactic oral AMU in neonatal lambs, farmers could be informed about the percentage of farmers who carry out that practice. However, this would only work if the behaviour is not highly prevalent in a population, otherwise the norm that oral prophylactic AMU is acceptable could be reinforced (Cislaghi and Heise, 2018). The research can also be used to determine the acceptability of different intervention types. For instance, restrictive and legislation based interventions would not be acceptable to farmers as they thought this would be detrimental to animal welfare.

Finally, a complex relationship between farmers and veterinarians in regards to AMU was identified in this research. The veterinarian perspective on this relationship warrants further investigation in particular. Findings from the veterinarian prescribing survey could be used to develop a qualitative study around the development of the veterinarian-farmer trust relationship in regards to AMU. This would allow for a more in-depth understanding of veterinary antimicrobial prescribing behaviour.

10.6. Conclusions

The findings presented in this thesis have improved the understanding of how antimicrobials are used, and provided evidence for the presence of AMR, on sheep and beef farms in the UK. Using a mixed-methods, multidisciplinary approach, seven studies were conducted to investigate farmers' recording practices, on-farm AMR patterns, and veterinarian and farmer antimicrobial decision-making. The importance of recording and interpreting data was a key theme that emerged across the studies and had important industry and policy implications in terms of how AMU targets are set and how AMU and AMR should be measured on sheep and beef farms. The identification of common factors in farmers' AMU decision-making provided useful evidence for the development of future intervention studies. Improved medicine recording, AMR surveillance, and further understanding of the relationship between farmers and veterinarians is important to ensure optimal antimicrobial stewardship on sheep and beef farms in the UK.

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12. Appendices

Appendix 1: Information sheet with consent form for farmers taking part in the longitudinal study (Studies 1, 2, and 7)

STUDY INFORMATION

DATE: _____

We are inviting you to take part in a research project on antimicrobial use on sheep and beef farms. Before you decide to take part, it is important you understand exactly what data we are collecting from you and what we'll do with it. Please read the information below.

What is the purpose of the study?

There are three aims to this study:

1) To quantify antibiotic use in sheep and beef farms.
2) To understand the decision-making of farmers regarding antimicrobials.
3) To look for antibiotic resistance patterns on the farm.

Why have I been invited to participate?

We are inviting you to participate in this study because you previously completed our survey "Sainsbury's Beef Development Group - 2017 Management Survey", where you said you were willing to share your antibiotic usage data. You were then contacted by ABP to discuss taking part in a longitudinal study. We want to include antibiotic use from a diverse range of farms, so are asking 50 farms from around to UK to take part.

Do I have to take part?

Your participation is voluntary and there is no obligation to take part. You can opt in to participate in this study by returning the consent form below. You are free to withdraw from this study at any time by emailing charlotte.doidge@nottingham.ac.uk.

Will the information I provide be confidential?

Yes. All information you provide will be completely confidential and used solely for research purposes in accordance with the General Data Protection Regulation 2016. During the study data will be stored at the University of Nottingham on a password-protected computer file and will be accessed only by the researchers working on the project at University of Nottingham, ABP and Sainsbury's. Stored data about your farm will be anonymous and not stored with your name, farm name, or address. You will not be able to be identified or identifiable in any reports or publications.

What will be the benefits and disadvantages of this study?

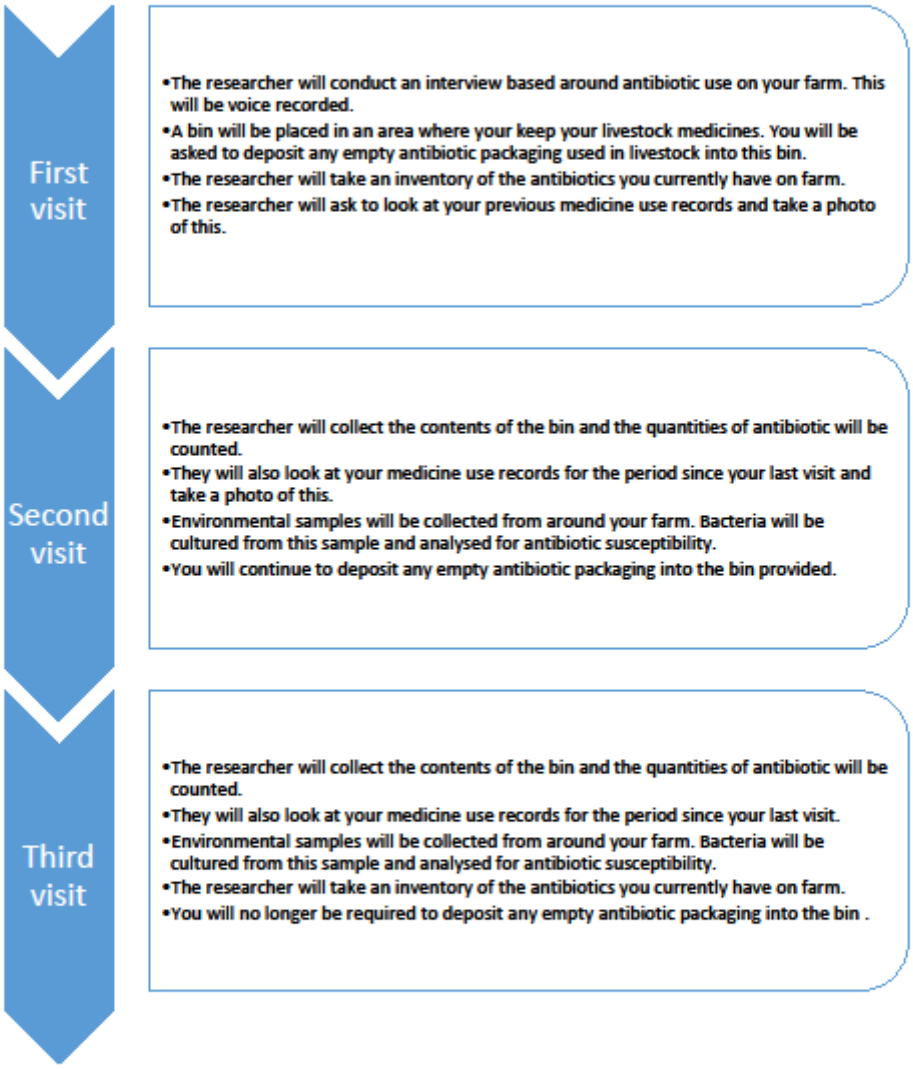
By participating in this study, you will be helping us to better understand how antibiotics are used on sheep and beef farms. You will be contributing to one of the most robust evidence base for responsible antibiotic usage in the UK sheep industry. It can also act as a free independent review of your on farm antibiotic usage which is a new part of Farm Assurance. The research does not involve any investigations that might put you at risk.

Who is conducting this research?

The research team includes Charlotte Doidge, Dr Jasmeet Kaler, Dr Chris Hudson and Dr Fiona Lovatt from the University of Nottingham. The research is commissioned and funded by AHDB Beef and Lamb.

What will happen to me if I take part?

A researcher will visit your farm 3 times within a one year period, with the first visit in December 2018. Below is an outline of what will happen at each visit:



What will happen to the results of this study?

The results of this study will be presented in farming and academic publications. Data will also be used as part of a PhD thesis. Sainsbury's Development Group will receive information - which will not be anonymous - on the quantities of antibiotics, and types of antibiotics you have used over the 1 yearlong study period. If you are interested in

viewing a summary of the results of this study please contact Charlotte Doidge at charlotte.doidge@nottingham.ac.uk.

Who can I contact if I have a question about the study?

If you have any questions about the project then please contact Charlotte Doidge in the first instance, using the email address charlotte.doidge@nottingham.ac.uk.

Who has reviewed this study?

This study has been reviewed and given favourable opinion by the University of Nottingham's Research Ethics Committee.

Your data protection rights

The University of Nottingham is the data controller and Mr Simon Gill is the University of Nottingham's Data Protection Officer. In accordance with the General Data Protection Regulation, you have the right to access the data we hold about you. You also have the rights to erasure, correction, portability and restriction of processing of your data. The legal basis for processing your personal data on this occasion is Article 6(1a) consent of the data subject. You have the right to lodge a complaint with the Information Commissioner's Office (ICO). The University may store your data for up to 25 years and for a period of no less than 7 years after the research project finishes. The researchers who gathered or processed the data may also store the data indefinitely and reuse it in future research.

Informed consent for Longitudinal Study

1. Taking part in the study

	Yes	No
I have read the information sheet and understood the information about the project. I have been given the opportunity to ask questions and my questions have been answered to my satisfaction.	☐	☐
I consent voluntarily to be a participant for this study and understand that I can withdraw at any time without giving reason and without penalty.	☐	☐
I understand that taking part in this study involves an audio recorded interview.	☐	☐
I understand that taking part in this study involves depositing antibiotic packaging used in livestock into bins.	☐	☐
I understand that taking part in this study involves a researcher taking environmental samples from my farm.	☐	☐

2. Use of the information in the study

	Yes	No
I understand that information I provide will be used anonymously for reports, publications and as part of a thesis.	☐	☐

I understand that personal information collected about me that can identify me, such as my name or where I live, will not be shared beyond the study team and Sainsbury's Development Group. ☐ ☐

I agree that my information can be anonymously quoted in research outputs. ☐ ☐

3. Future use and reuse of the information by others

	Yes	No
I give permission for the anonymised transcripts, antibiotic usage data and environmental sample data to be stored at the University of Nottingham on a password-protected computer file so it can be used for future research and learning.	☐	☐

4. Signatures

Name of participant (In CAPITALS)	Signature	Date

I have shown the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

Name of researcher (In CAPITALS)	Signature	Date

5. Study contact details

Charlotte Doidge
PhD Student
School of Veterinary Medicine and Science
The University of Nottingham
Sutton Bonington Campus
LE12 5RD

Charlotte.doidge@nottingham.ac.uk

Jasmeet Kaler
Primary Supervisor
School of Veterinary Medicine and Science
The University of Nottingham
Sutton Bonington Campus
LE12 5RD

Jasmeet.kaler@nottingham.ac.uk

Appendix 2: Ethics form for studies 1, 2, 3, 4, 5 and 7

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

School of Veterinary Medicine and Science
Research Project Review form

The Research Project Review form **should be completed for all PGR and staff research projects**, irrespective of whether funding is being sought or not for the project, and should be submitted to: SV-research@nottingham.ac.uk as early as possible (in advance of any project commencing and/or prior to any funding application being made) for School review.

Submission Checklist: To facilitate review, please confirm which sections have been completed for your research project

Section	Requirement	Completed
Section 1: Research Project and Funding Details	To be completed for all projects	☒
Section 2: Clinical Research	To be completed only if the project includes the use of (non-human) clinical material or data obtained from veterinary practices	☐
Section 3: Health and Safety	To be completed for all projects	☒
Section 4: Postgraduate Research (PGR) Project and Supervisory Team Details	To be completed only if the project necessitates the appointment of a PGR student	☒
Section 5: Ethical Considerations	To be completed for all projects	☒

Supporting documentation (as relevant)	Attached
Clinical protocols (eg, diagnostic, treatment)	☐
Statement of Research Ethics	☐

Section 1: Research Project and Funding Details

SVMS Lead:	Jasmeet Kaler
Principal investigator?	Yes ☒ No ☐ If No, please indicate PI (School, Institution):
Other Co-Is / collaborators (affiliation):	Chris Hudson, Fiona Lovatt Helen West (Biosciences)
Project title:	Antimicrobial usage on sheep and beef farms
Is funding (external/ internal) being sought for this project?	Yes ☒ No ☐
Intended funder and funding scheme:	SRA money

V1.0, Approved 12.12.2016

Submission deadline:	ASAP	**Funding sought (approx.):**	**NA**
Details of any commitments required from the School:	(e.g. office/lab space, technician time, match-funding for Studentship / Fellowship, equipment, etc)		
Details of any equipment requests over £10,000:			
Has this or a related project been submitted to this or another funder before?	Yes ☒ No ☐ If Yes, please provide brief details and indicate how the reviewers comments have been addressed:		
Please suggest up to 3 UoN peer-reviewers for the funding application:	1) 2) 3)		
Other peer support requested:	Grant clinic / Presentation to School / Mentorship / Other (please specify)		

Research Project Outline

Please provide a one page outline of the research project with a statement of why the work is important (novelty and timeliness), hypotheses (if any), objectives, experimental plan/methodology and techniques to be used

The project is part of an AHDB funded PhD. Specifically it relates to one year longitudinal study (already investigating antimicrobial usage on sheep and beef farms across England and Wales). Antimicrobial usage data from 38 farms is being collected using farm medicine records and bin depositories. The aim of this study is to study the prevalence and patterns of antimicrobial resistance on these farms and link it back to the antimicrobial usage information collected via the bin method in the longitudinal study.

The review form is for the microbiological part of the study which is new added and will be conducted in collaboration with Helen West. Funder has agreed to this.

I have attached previously approved ethics and PG committee form.

Section 2: Clinical Research

This section should be completed for all research projects that involves the use of (non-human) clinical material or data obtained from veterinary practices whether or not clinical associates: this includes cases, material or data obtained through veterinary practices or direct from owners, and seeing cases, making diagnoses or recommending treatment as part of a research project.

If the principal applicant is not MRCVS	

who is veterinary lead for the research team?	
Does this project involve cases beyond just those you would routinely see (i.e. collecting data from more than just your normal case load)	Yes ☐ No ☐ If yes, please indicate how cases/material will be recruited, dealt with (eg treated) and how (if applicable) individual results will be reported to referring vets and/or owners (reference may be made to information provided in Section 1):
Does this project involve the use of School vehicles or equipment?	Yes ☐ No ☐
If the project involves diagnostics, treatment or advice, will fees be charged?	Yes ☐ No ☐ If fees or subsidies are involved (or could be perceived as being involved), please describe how these will be handled:
Does the project involve Clinical Associates and/or other practices with existing formal agreements (eg MoU) with SVMS, or clients of those practices?	Yes ☐ No ☐ If the project involves practices other than Clinical Associates, give details of practices to be involved:
If protocols are to be applied (eg particular diagnostic or treatment protocols), please attach those protocols using the format in which they will be distributed. If these are still in a draft state, the final versions may be needed before final approval is given. Include details of how Clinical Associates and School clinicians will be involved in the project	

Section 3: Health and Safety

Will this project involve the use of Drones (UAVs) for any part of the research? UoN policy and other guidance can be found at http://www.nottingham.ac.uk/safety/policies-and-guidance/drones/drones.aspx	Yes ☐ No ☒ If Yes, please ensure compliance with Civil Aviation Authority and UoN policy and that the relevant risk assessment is completed prior to initiation of the research project
Will this project involve the use of University laboratories?	Yes ☒ No ☐
Is the project covered by the appropriate risk assessment?	Yes ☒ No ☐ If No, please prepare a risk assessment prior to initiation of the research project
Does the project involve genetically modified organisms?	Yes ☐ No ☒ If Yes, please note that this may require a separate risk assessment to be prepared

If the project involves pathogens not previously used in the School, please provide details	

Section 4: Postgraduate Research (PGR) Project and Supervisory Team Details

Qualification aimed for:	PhD / MRes / DVM / MVM
Study type:	Full-time / Part-time
PGR Project Title: (if different from that given in Section 1)	
Source of funding for studentship, funding splits (if relevant), elements supported and values: eg, 50% external funder: 50% School for HEU fees, RCUK stipend and running costs of £XX pa eg, 100% Commonwealth PhD Scholarship for developing countries, OS fees at highest banding, stipend paid directly to candidate by funder	Funder(s) (% splits): Annual stipend to be paid (if relevant): £
Duration of funding for studentship:	
Proposed start date:	
Anticipated interview date:	
Student Name under consideration:	
Application already made via the Portal	Yes ☐ No ☐

Supervisory team (affiliation)	**Role**	**% credit split**	**Number of PGR students in the last 7 years who have:**		**Date last attended PGR Supervisor workshop**
			Successfully submitted within time period	**Failed, or failed to submit within time period**	
	Primary				
	Co-Supervisor				
	Co-Supervisor				
	Co-Supervisor				

Note: The primary supervisor will have day to day responsibility for the student and will be the route for communication with the post-graduate committee. The primary supervisor must have attended a post-graduate supervision workshop within the last 5 years and have completed a degree equivalent to the qualification being aimed for. The supervisory team should comprise at least two SVMS Supervisors.

Project aims: Provide brief details of aims and/or hypothesis and research questions being addressed (if these differ to that detailed in Section 1)

Background and Relavence:

Antimicrobial resistance is an increasing problem in both human and veterinary medicine. Internationally, this has been identified as a key concern by the EU, FAO, OIE, G7 and G20. Antimicrobial usage is thought to be associated with selection for antibiotic resistance. Nationally and internationally there is substantial drive to reduce the use of antibiotics – for example, the WHO Global Action Plan expects every country in the world to have an action plan to reduce in antimicrobial usage by mid-2017. Pressure on reducing the need for use

of antibiotics in animal health is increasing. This is also reflected in the recent paper on agriculture and the environment, published as part of the Independent AMR Review by Lord O'Neill.

However, promoting reduction in antimicrobial usage requires benchmarking data on the usage pattern, and understanding of practices around their usage and prescription. Though total antimicrobial usage in sheep production is assumed to be small compared to other production animals, **there is no data benchmarking farms against similar types, quantifying usage on sheep farms or exploring how farmers are using antimicrobials and how vets are prescribing them.**

Areas that specifically need investigation in terms of usage include in-lamb ewes, where antibiotics are sometimes given metaphylactically to reduce impact of an abortion storm, and especially metaphylactic usage in neonatal lambs. Anecdotal reports of metaphylactic treatment of ewes for for footrot are also rising (although the recommended method is to treat individuals early, Kaler et al., 2010). It is possible that the total usage of antibiotics for lameness (therapeutic or metaphylacic) can be reduced if other methods of prevention (e.g. culling, quarantine) are used. However, robust evidence regarding antimicrobial usage on sheep farms is required to: a) **Replace** the need for the use of antibiotics b) **Reduce** the annual usage of antibiotics whilst preserving health and welfare

It is critical at this time that the industry is seen to be taking proactive and meaningful steps to limit the risk of development of AMR. By doing so, the potential for imposition of "top down" legislative approaches (such as limitations on total antimicrobial use per unit production or withdrawal of particular compounds or families) will be reduced and the potential for an industry-led approach increased.

The overall aim of this project is use multiple data sources to quantify model antimicrobial usage on sheep farms and understand farmer and vet decision making on using antimicrobials to promote responsible use of antimicrobials

Objectives:

The objectives of the research are:

1. To use a cross-sectional study of 800 commercial producers with on-farm and production data to understand a) antimicrobial usage, b) types of antimicrobial used, c) ways in which they are being used (curative, metaphylactic, prophylactic), and d) practices and perceptions around their usage
2. To follow 25 intensively recording flocks (who are recording data via a smartphone app currently being trailed on farms as part of Innovate project) including antimicrobials used and quanitity) and 25 randomly selected farms from objective 1 over a one year period to estimate the usage patterns (accounting for other species) and antimicrobial use as quantified as treatment incidence (T.I.). Treatment incidence expresses how many animals per 1000 receive a daily dose of an antibiotic on a farm.
3. To gather data through questionnaire and practice records from vets associated with the 50 farms described under objective 2, and understand prescribing practices of sheep vets.
4. To collect faecal samples and correlate resistance patterns to Antimicrobial usage(NEW)

Methodology: Provide brief details about how the research questions will be answered (if these differ to that detailed in Section 1)

Project data, questions and techniques:. The project will use 3 different datasets to achieve its objectives a) data collected from the 800 sheep producers (supplying Sainsbury's) will contribute to objective 1. We will then use 25 (EID) farms and 25 non EID

farms that will be followed for a year to calculate usage of antimicrobials. We will quantify this as treatment incidence or other standardised estimates such as Daily Dose Animal (DDA), antimicrobial exposure rate. The prescribing data for those farms will be collected from associated vet practices (after agreement with farmer) and we will do a questionnaire with vets to understand their prescribing patterns.
Above data will be used to answer various key gaps in our knowledge : Benchmarks for different types of flocks and usage for sheep (accounting for what other livestock is there (e.g. beef)), comparing results of different ways of measuring antimicrobial use (e.g. how well does total mg use per kg animal correlate with DDA etc.)?, potential for estimating antimicrobial usage from different sources of data (e.g. vet practice records). What are the treatment level and farm-level variables associated with rate of antimicrobial usage? (explored through multilevel modelling of data)

Techniques: Project will use epidemiological techniques in terms of study design, collection of data. Bespoke models will be formed to compare different ways of measuring antimicrobial usage though data, their precision and predictive models of variables associated with antimicrobial usage on farms.

The study will involve collecting sheep and beef cattle faecal samples from a selected field from each farm. The faecal samples will be collected at two time periods, around six months apart (Spring/Summer and Autumn/Winter). The faecal samples will be processed in order to isolate coliforms. These coliforms will then undergo antimicrobial susceptibility testing against twelve antimicrobials using the disc diffusion method. Number of samples will depend on combination of feasibility and management at time of visit.

Techniques: Provide brief list of techniques the PGR student will develop. For each technique undertake a brief risk analysis (uses novel techniques, uses novel primers, tissues difficult to obtain, clinical information may be lacking – not health and safety risks) and what steps have been and will be undertaken to mitigate against those risks (alternative techniques, pilot data, agreed source of tissues)

Technique	Risk analysis	Mitigation against risks
Microbiological analysis	**Lack to enough or relevant data**	**Methods used have been developed and being for similar AMR project (NERC)**

Milestones and outputs: Provide detail of key milestones and outcomes (reports, papers etc) for this student. This will be reviewed at each annual review to confirm progression

Milestone / output	Completion date
Final farm visit for sample collection period 1	01/07/2019
End of antimicrobial susceptibility testing	28/02/2020

End of antimicrobial susceptibility testing	28/02/2020
Finish analysis	01/05/2020
Year 1 Review	
Year 2 Review	
Year 3 Review	
Thesis writing	

Section 5: Ethical Considerations

Please describe in a sentence or two, in this box, any details that will help the reviewers interpret the form:
Collection of faecal samples from the field

Has this or a similar research project been reviewed previously?	Yes ☒ No ☐ If Yes, please indicate previous project approval number:
For minor/major amendments to previously approved research projects, please outline significant changes made to the project that give rise to ethical issues and briefly indicate how these will be addressed: The only change in the project is collection of faecal samples from the field Attached is the ethical review approved The work will be conducted in the Biosciences lab where already similar work is ongoing under the supervision of Helen West. Charlotte has conducted lab induction from Biosciences.	

Section 1. Data collection		
Q1. Does the proposed study involve obtaining information by questionnaire, interview or focus group?	Yes ☐	No ☒ Go to Q2
If yes: Have you read, understood and agree to abide with the School's policy on data collection by questionnaire, interview or focus group?* Have you attached a Statement of Research Ethics?* *Documents can be found at https://workspace.nottingham.ac.uk/display/VMaS/Research or S:\MHS\Veterinary\Research\Ethic		Yes ☒ Yes ☒
Q2. Does the proposed study involve obtaining 'owned' information through a third party – e.g. searching practice records about clinical cases?	Yes ☐	No ☒

If yes: Have you read the relevant sections of the EU General Data Protection Regulation (GDPR) and the UK Data protection act (2018) as they relate to your proposed work and, do you understand the implications of data protection and agree that the proposed study is compliant? **GDPR (UoN):** https://www.nottingham.ac.uk/governance/records-and-information-management/gdpr-overview.aspx **DPA 2018:** http://www.legislation.gov.uk/ukpga/2018/12/contents/enacted	Yes ☒

Section 2. Human material		
Q3. Does the proposed project involve human material (including primary cell lines)?	Yes ☐	No ☒ go to section 3
If yes, please provide more details about the material to be used (this information will be forwarded to Cinzia Allegrucci, HTA contact):		

Section 3. Animal material		
Q4. Does the proposed project use animals or materials obtained from them?	Yes ☒ go to Q5	No ☐ go to end
Q5a. If yes to Q4, what is the source of the animals and animal derived material to be used in the proposed study (e.g. cadaver)? Env faecal samples		
Q5b. If yes to Q4, is there a process in place for obtaining informed owner consent (forms for collecting abattoir material are available from Jes Squires /clinical technician).	Yes ☒	No ☐
Q6. Have you read and understood what types of study are regulated by ASPA, and what a regulated procedure is, by reading **the short paragraph in Section 1.1 of the** Guidance on the Operation of the Animals (Scientific Procedures) Act	Yes ☒	No ☐
Q7. Is any aspect of the proposed project to be carried out under the Animal (Scientific Procedures) Act?	Yes ☐	No ☒ go to Q8
If Yes, please provide Home Office Project Licence Number and protocol number.	PPL	
If **no Project Licence in place,** please consult with the Director of the BSU **or his nominee** as this must go for review to the A(SP)A University AWERB committee. Contact via this email: bsu@nottingham.ac.uk		

V1.0, Approved 12.12.2016

Note: If humane killing is to be undertaken, individuals must be appropriately trained and educated to allow them to be entered onto the University of Nottingham Register as competent to kill animals for a scientific purpose including at a POLE (**successful completion of Module K Function D**). Please contact the Named Training and Competency Officer (NTCO) for details of the training course and subsequent assessment. Contact via this email: bsu@nottingham.ac.uk		
Q8. Is any aspect of this work to be performed outside of the UK **that would otherwise be regulated under the Animals (Scientific Procedures) Act?**	Yes ☐	No ☒
If Yes, please consult with the Director of BSU or his nominee as this must go for review to the University AWERB committee.		
If the work is to be undertaken outside the UK, please state the country involved.		
Q9. Is any aspect of the proposed project to be carried out under the Veterinary Surgeon's Act (i.e. uses samples or part of samples obtained from animals using an invasive procedure, which includes surplus samples taken as part of a clinical investigation)?	Yes ☐	No ☒ go to Q10
If yes, what is the source of the animals or animal derived material to be used in the proposed study? Describe in detail the process by which samples are to be obtained – site, amount concurrent medication (e.g. sedation), restraint, clipping of fur etc.		
Is there a process in place for obtaining informed owner consent?	Yes ☐	No ☐
Q10. Does the proposed project involve modification of the behaviour or routine of any animals?	Yes ☐	No ☒ go to Q11
If yes, please describe these modifications and the potential impacts on the animals:		
Q11. Have you read and understood the ARRIVE (animal research: reporting *in vivo* experiments) guidelines at http://www.nc3rs.org.uk/page.asp?id=1357 ?		Yes ☒ N/A ☐

Declaration
I confirm that the information provided is true and complete to the best of my knowledge and the project described above complies with published codes of conduct, ethical principles and guidelines of professional bodies associated with my research discipline.

Signature of Applicant:

Jasmeet Kaler..... Date:25th February 2019 ...

Approval signature (on behalf of ethical review panel):

..... Date: .....

V1.0, Approved 12.12.2016

Appendix 3: Information collected at the end of the longitudinal study (Study 1)

Farm no: **Study start date:** **End date:**

BEEF

Treatment of disease:

- How many cases of the following health problems have you treated with antibiotics since the beginning of the study?
  - Pneumonia:
  - Lameness:
  - Mastitis:
  - Retained placenta/metritis:
  - Calf diarrhoea:

SHEEP

- Since the beginning of the study, how many ewes (not including ewe lambs) were put to the ram?
- How many Lambs did you sell to slaughter in since the beginning of the study?
- How many Lambs did you sell as stores in since the beginning of the study?
- How many Lambs did you sell for Breeding (M and F) in since the beginning of the study?
- How many Lambs did you retain for breeding in since the beginning of the study?
- How many lambs were born at your most recent lambing?
- Antibiotic ORAL treatments used in lambs less than a week old
  - How many lambs were given a single oral treatment? (lambs less than a week old only)
  - How many lambs were given a second oral treatment? (lambs less than a week old only)
  - How many lambs were given a third oral treatment? (lambs less than a week old only)
- Antibiotic INJECTABLE treatments used in lambs less than a week old
  - How many lambs were injected once with antibiotics? (lambs less than a week only)
  - How many lambs were injected twice with antibiotics? (lambs less than a week only)
  - How many lambs were injected three times with antibiotics? (lambs less than a week only)

Treatment of disease:

- How many cases of the following health problems have you treated with antibiotics since the beginning of the study?
  - Watery mouth:
  - Lameness:
  - Mastitis:
  - Joint ill:
  - Lambing problems in ewes:

QUALITATIVE QUESTIONS:

- How did you control watery mouth in your flock this year, if at all? (sheep)
- Can you describe your experience of antibiotic recording over the study period?
- Can you describe your experience of using the antibiotic bin over the study period?
- Tell me about your experience of taking part the study in terms of your views on antibiotics?
- Can you describe what an antibiotic is?

Appendix 4: Recruitment letter and information sheet for Study 3

University of Nottingham
UK | CHINA | MALAYSIA

AHDB
BEEF & LAMB

XXX

Practice ID: 1

A survey on your decisions on prescribing antibiotics to sheep and beef producers

I am writing to you on behalf of The University of Nottingham and AHDB Beef and Lamb. We are collecting data as part of a PhD research project, to understand more about vet decision making in regards to prescribing antibiotics to sheep and beef producers. As your practice is listed as able to treat sheep and cattle on the RCVS records, we invite you to complete the enclosed survey.

The survey will take approximately 15 minutes to complete. It is important to note that the survey responses are completely confidential, and any information you provide will be used in research anonymously. There are **no right or wrong answers**. Please answer as truthfully as possible, as this will help us to gain a more accurate understanding of the factors involved in the vet decision making process when prescribing antibiotics.

I would be grateful if vets in your practice that work with sheep and cattle could complete the enclosed survey and return using the stamped, addressed envelope provided. There are three copies enclosed. However, if you require more, please contact Charlotte Doidge at charlotte.doidge@nottingham.ac.uk.

More information about the survey can be found in the study information sheet overleaf. If you have any further questions regarding this survey, you can contact me using the email address listed above.

Thank you for taking the time to fill in this survey.

Charlotte Doidge

PhD Student, University of Nottingham

Dr Jasmeet Kaler

Primary Supervisor, University of Nottingham

STUDY INFOMATION

VET DECISION MAKING SURVEY: ANTIMICROBIAL PRESCRIBING TO SHEEP & BEEF PRODUCERS

Why have I been invited to participate?

We are inviting you to participate in this study because your veterinary practice is listed as able to treat sheep and cattle on the RCVS website, where we selected your practice name and address. We want to include the opinions of a diverse range of vets, so all practices that are RCVS registered in the UK that treat sheep and cattle have been invited to take part.

Do I have to take part?

Your participation is voluntary and there is no obligation to take part. If you choose to participate, by returning a completed survey, you are giving consent for the information you have supplied to be used in this study. You are free to withdraw from this study at any time.

Will the information I provide be confidential?

Yes. All information you provide will be completely confidential and used solely for research purposes in accordance with the 1998 Data Protection Act. You will not be able to be identified or identifiable in any reports or publications. During the study data will be stored at the University of Nottingham and will be accessed only by the researchers working on the project. Stored data about your prescribing practices will be anonymous and not stored with your practice name or address.

What will be the benefits and disadvantages of this study?

There is currently a lack of information on how vets decide to prescribe antibiotics to sheep and beef producers. We need to understand more about what factors are important in this vet decision making process. If you are interested in viewing a summary of the results of this survey please contact Charlotte Doidge using the information overleaf. The research does not involve any investigations that might put you at risk.

Who is conducting this research?

The research team includes Charlotte Doidge, Dr Jasmeet Kaler, Dr Chris Hudson and Dr Fiona Lovatt from the University of Nottingham. The research is commissioned and funded by AHDB Beef and Lamb.

Who can I contact if I have a question about the study?

If you have any questions about the project then please contact Charlotte Doidge in the first instance, using the information overleaf.

Who has reviewed this study?

This study has been reviewed and given favourable opinion by the University of Nottingham's Research Ethics Committee.

Thank you for considering taking part in this survey

Appendix 5: Example survey for Study 3

University of Nottingham
UK CHINA MALAYSIA

AHDB
BEEF & LAMB

VET DECISION MAKING SURVEY: ANTIMICROBIAL PRESCRIBING TO SHEEP & BEEF PRODUCERS

Section A: About you and your vet practice

1. **Please indicate your gender.**

☐ Male ☐ Female ☐ Prefer not to say ☐ Other

2. **What is your age group?**

☐ 20-30 ☐ 31-40 ☐ 41-50 ☐ 51-60 ☐ 61-70 ☐ 71+

3. **What year did you graduate with your veterinary degree?**

☐ Pre 1970 ☐ 1971-1980 ☐ 1981-1990 ☐ 1991-2000 ☐2001-2010 ☐ After 2010

4. **From which university did you graduate with your veterinary degree?**

☐ Bristol ☐ Cambridge ☐ Edinburgh ☐ Glasgow ☐ Liverpool ☐ Nottingham ☐ RVC

☐ Other (Please specify) _____

5. **How many vets are currently employed in your practice?** (Please provide a number of all vets that are employed at your primary site of work, including all species)

Full time: _____ Part time: _____

6. **What region is your practice in?**

☐ SW England ☐ SE England ☐ Central England ☐ NW England ☐ NE England

☐ N Scotland & Highlands ☐ S & Central Scotland ☐ N Wales ☐ S Wales ☐ N Ireland

7. **What is your position within the practice?**

☐ Practice partner ☐ Associate/Clinical lead ☐ Assistant ☐ Locum

8. **What type of practice are you employed in?**

☐ Farm ☐ Farm & Equine ☐ Farm & Small Animal ☐ Farm, Equine & SA

9. **What type of work are you involved in within your practice?**

☐ Farm ☐ Farm & Equine ☐ Farm & Small Animal ☐ Farm, Equine & SA

10. **What percentage of your time do you spend working with cattle and sheep?**

Dairy Cattle: _____% Beef Cattle: _____% Sheep: _____%

11. **What percentage of your work with sheep and cattle clients is spent in a disease prevention advisory role?**

Dairy Cattle: _____% Beef Cattle & Sheep: _____%

Section B: More about you

Below are a list of statements relating to personality traits that may or may not apply to you. In the table below please tick a box to explain how well the pairs of words describe you, even if one characteristic applies more strongly than the other. Answer as honestly as you can. There are no right or wrong answers. Please only tick one box per row.

I see myself as:

Characteristics	Strongly disagree	Moderately disagree	Disagree a little	Neither agree nor disagree	Agree a little	Agree moderately	Strongly agree
Extraverted Enthusiastic							
Critical Quarrelsome							
Dependable Self-disciplined							
Anxious Easily upset							
Open to new experiences Complex							
Reserved Quiet							
Sympathetic Warm							
Disorganised Careless							
Calm Emotionally stable							
Conventional Uncreative							

Section C: Scenarios

Section C starts over the page. You will be presented with eight different scenarios that may be seen in practice. Changes in each scenario are indicated by ***bold, italic font***. You will be asked to rate the likelihood that the vet in the scenario would prescribe antibiotics, and what percentage of vets you think would prescribe antibiotics.

In all instances, the antibiotic is **licensed for use in that animal**, and is **not a high priority critically important antibiotic (HP-CIA)**.

In the UK, fluoroquinolones, 3rd and 4th generation cephalosporins and colistin are recognised as high priority CIAs, as designated by the European Medicines Agency.

«Unique_ID»-«Practice_ID»-«BlockNum1»

Scenario 1

A farmer comes into the vet practice asking for a bottle of particular antibiotic as he ***wants to prevent calf pneumonia in a group of home-born calves*** on the farm. The farmer says that they ***have never used this antibiotic for this reason before, but have used it on the farm for a different reason.***

The farmer has been a client at the vet practice for ***less than a year and the vet has visited the farm once. Other vets in the practice have prescribed*** the farmer this antibiotic without a farm visit before, but the farmer ***is happy to pay for a vet visit if needed.***

The vet ***is not running late*** for their afternoon consults, and ***is not confident*** in the farmers' judgement of disease.

A) Based only on the information provided above, how likely or unlikely is the vet to prescribe the farmer with the antibiotic without visiting the farm first? (Please circle)

Definitely would not prescribe					Not sure					Definitely would prescribe
-5	-4	-3	-2	-1	0	1	2	3	4	5

B) What proportion of vets do you think would prescribe this farmer antibiotics without visiting the farm first? (Please indicate by drawing a line in the scale)



Scenario 2

A farmer comes into the vet practice asking for a bottle of particular antibiotic as he ***wants to prevent calf pneumonia in a group of home-born calves*** on the farm. The farmer says that they ***use this antibiotic the same time every year.***

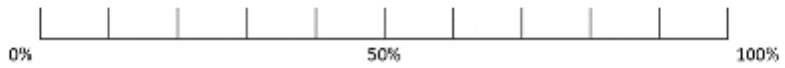
The farmer has been a client at the vet practice for ***10 years and the vet rarely visits the farm. No other vet in the practice has prescribed*** the farmer this antibiotic without a farm visit before, but the farmer ***does not want to pay for a vet visit.***

The vet ***is not running late*** for their afternoon consults, and ***is not confident*** in the farmers' judgement of disease.

A) Based only on the information provided above, how likely or unlikely is the vet to prescribe the farmer with the antibiotic without visiting the farm first? (Please circle)

Definitely would not prescribe					Not sure					Definitely would prescribe
-5	-4	-3	-2	-1	0	1	2	3	4	5

B) What proportion of vets do you think would prescribe this farmer antibiotics without visiting the farm first? (Please indicate by drawing a line in the scale)



Scenario 3

A farmer comes into the vet practice asking for a bottle of particular antibiotic as he ***suspects multiple cases of watery mouth*** on the farm. The farmer says that they ***have never used this antibiotic for this reason before, but have used it on the farm for a different reason.***

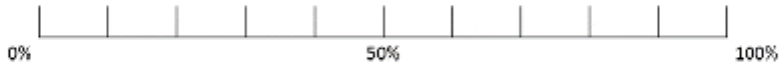
The farmer has been a client at the vet practice for ***10 years and the vet regularly visits his dairy herd but not as involved with the sheep or beef cattle. Other vets in the practice have prescribed*** the farmer this antibiotic without a farm visit before, but the farmer ***does not want to pay for a vet visit.***

The vet ***is not running late*** for their afternoon consults, and ***is not confident*** in the farmers' judgement of disease.

A) Based only on the information provided above, how likely or unlikely is the vet to prescribe the farmer with the antibiotic without visiting the farm first? (Please circle)

Definitely would not prescribe					Not sure					Definitely would prescribe
-5	-4	-3	-2	-1	0	1	2	3	4	5

B) What proportion of vets do you think would prescribe this farmer antibiotics without visiting the farm first? (Please indicate by drawing a line in the scale)



Scenario 4

A farmer comes into the vet practice asking for a bottle of particular antibiotic as he ***suspects multiple cases of calf pneumonia*** on the farm. The farmer says that they ***use this antibiotic the same time every year.***

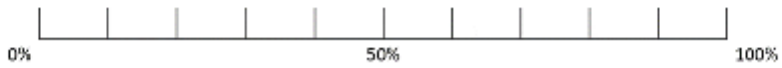
The farmer has been a client at the vet practice for ***less than a year and the vet has visited the farm once. No other vet in the practice has prescribed*** the farmer this antibiotic without a farm visit before, but the farmer ***does not want to pay for a vet visit.***

The vet ***is running late*** for their afternoon consults, and ***is confident*** in the farmers' judgement of disease.

A) Based only on the information provided above, how likely or unlikely is the vet to prescribe the farmer with the antibiotic without visiting the farm first? (Please circle)

Definitely would not prescribe					Not sure					Definitely would prescribe
-5	-4	-3	-2	-1	0	1	2	3	4	5

B) What proportion of vets do you think would prescribe this farmer antibiotics without visiting the farm first? (Please indicate by drawing a line in the scale)



Scenario 5

A farmer comes into the vet practice asking for a bottle of particular antibiotic as he ***suspects multiple cases of calf pneumonia*** on the farm. The farmer says that they ***have never used this antibiotic for this reason before, but have used it on the farm for a different reason.***

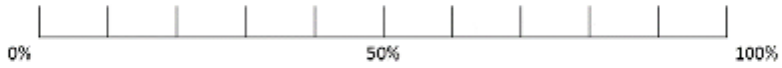
The farmer has been a client at the vet practice for ***10 years and the vet regularly visits his dairy herd but not as involved with the sheep or beef cattle. No other vet in the practice has prescribed*** the farmer this antibiotic without a farm visit before, but the farmer ***does not want to pay for a vet visit.***

The vet ***is running late*** for their afternoon consults, and ***is not confident*** in the farmers' judgement of disease.

A) Based only on the information provided above, how likely or unlikely is the vet to prescribe the farmer with the antibiotic without visiting the farm first? (Please circle)

Definitely would not prescribe					Not sure					Definitely would prescribe
-5	-4	-3	-2	-1	0	1	2	3	4	5

B) What proportion of vets do you think would prescribe this farmer antibiotics without visiting the farm first? (Please indicate by drawing a line in the scale)



Scenario 6

A farmer comes into the vet practice asking for a bottle of particular antibiotic as he ***wants to prevent watery mouth in a group of home-born lambs*** on the farm. The farmer says that they ***use this antibiotic the same time every year.***

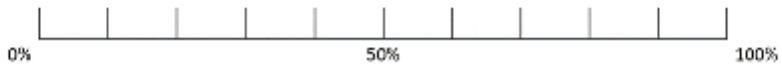
The farmer has been a client at the vet practice for ***10 years and the vet rarely visits the farm. Other vets in the practice have prescribed*** the farmer this antibiotic without a farm visit before, but the farmer ***is happy to pay for a vet visit if needed.***

The vet ***is running late*** for their afternoon consults, and ***is confident*** in the farmers' judgement of disease.

A) Based only on the information provided above, how likely or unlikely is the vet to prescribe the farmer with the antibiotic without visiting the farm first? (Please circle)

Definitely would not prescribe					Not sure					Definitely would prescribe
-5	-4	-3	-2	-1	0	1	2	3	4	5

B) What proportion of vets do you think would prescribe this farmer antibiotics without visiting the farm first? (Please indicate by drawing a line in the scale)



Scenario 7

A farmer comes into the vet practice asking for a bottle of particular antibiotic as he ***wants to prevent watery mouth in a group of home-born lambs*** on the farm. The farmer says that they ***have never used this antibiotic for this reason before, but have used it on the farm for a different reason.***

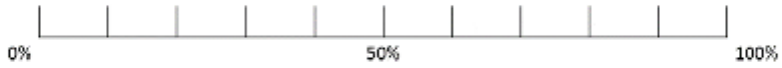
The farmer has been a client at the vet practice for ***10 years and the vet rarely visits the farm. No other vet in the practice has prescribed*** the farmer this antibiotic without a farm visit before, but the farmer ***is happy to pay for a vet visit if needed***.

The vet ***is not running late*** for their afternoon consults, and ***is confident*** in the farmers' judgement of disease.

A) Based only on the information provided above, how likely or unlikely is the vet to prescribe the farmer with the antibiotic without visiting the farm first? (Please circle)

Definitely would not prescribe					Not sure					Definitely would prescribe
-5	-4	-3	-2	-1	0	1	2	3	4	5

B) What proportion of vets do you think would prescribe this farmer antibiotics without visiting the farm first? (Please indicate by drawing a line in the scale)



Scenario 8

A farmer comes into the vet practice asking for a bottle of particular antibiotic as he ***suspects multiple cases of watery mouth*** on the farm. The farmer says that they ***use this antibiotic the same time every year.***

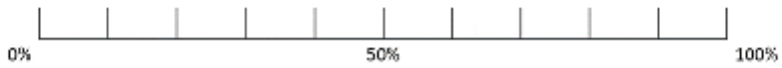
The farmer has been a client at the vet practice for ***less than a year and the vet has visited the farm once. Other vets in the practice have prescribed*** the farmer this antibiotic without a farm visit before, but the farmer ***is happy to pay for a vet visit if needed***.

The vet ***is running late*** for their afternoon consults, and ***is confident*** in the farmers' judgement of disease.

A) Based only on the information provided above, how likely or unlikely is the vet to prescribe the farmer with the antibiotic without visiting the farm first? (Please circle)

Definitely would not prescribe					Not sure					Definitely would prescribe
-5	-4	-3	-2	-1	0	1	2	3	4	5

B) What proportion of vets do you think would prescribe this farmer antibiotics without visiting the farm first? (Please indicate by drawing a line in the scale)



Section D: Your opinions on antibiotics

In the previous scenarios, the antibiotic requested was licensed in cattle and sheep, and not a high priority critically important antibiotic (HP-CIA).

In the UK, fluoroquinolones, 3rd and 4th generation cephalosporins and colistin are recognised as high priority CIAs, as designated by the European Medicines Agency.

Imagine if you had been requested to prescribe the antibiotics in the table below. Please indicate, using the tick boxes provided, whether your decision would have been any different.

Requested antibiotic	Much less likely to prescribe	Moderately less likely to prescribe	A little less likely to prescribe	Remain the same	A little more likely to prescribe	Moderately more likely to prescribe	Much more likely to prescribe
An antibiotic that was not licensed for that species							
A high priority critically important antibiotic (HP-CIA)							
A bottle of marbofloxacin for calf pneumonia							
An enrofloxacin oral doser for watery mouth							
Oxytetracycline tablets for watery mouth							

Section E: Further research

1. **Would you be willing to participate in further research into antimicrobial use for the University of Nottingham?** (e.g. sharing veterinary sales records)

   ☐ Yes ☐ No

2. **If you said yes, please provide the phone number and/or email address you would prefer to be contacted on:**

   Phone number: _____

   Email address: _____

Thank you for participating in this survey.

2017 Beef Management Survey

Introduction

Welcome to the 2017 Beef Survey Thank you very much for participating in this survey. We really appreciate the time and effort that you will put in to completing it. The aim of this survey is to gather information from across our supply base so that we can better understand our producers' systems and views surrounding various aspects of beef health and production. This questionnaire should take around 30 minutes to complete. If you cannot complete it all in one go you can return to it by clicking the 'Save and continue later' button at the bottom of each page.

Your Details

Please provide the following details for your farm *

Name *

Farm Name *

Business Name *

Postcode *

Completing the Survey

As you complete the survey, your answers will be automatically saved. If you wish to stop the survey and come back to complete later on, please click on the 'Save & Continue Later' button at the bottom of the page; this will send you a link to your email address where you can continue from where you previously got to.

You & Your Farm

What age category do you fall into? *

- [ ] 25 or under
- [ ] 26-45
- [ ] 46-65
- [ ] Over 65

Which of the following best describes your system? (Tick all that apply)

	Commercial	Pedigree	N/A
Conventional	☐	☐	☐
Organic	☐	☐	☐
Less Favoured Area	☐	☐	☐

Which of the following areas does your beef enterprise covers (tick all that apply) *

- ☐ Beef Suckler Herd
- ☐ Calf Rearing (bought in dairy/dairy X calves on milk)
- ☐ Growing and Finishing (bought in weaned calves / store cattle)

Other Enterprises

Please tick if you have any other livestock enterprises on your farm

- ☐ Sheep
- ☐ Dairy Herd
- ☐ Pigs
- ☐ Poultry
- ☐ Other (please specify):

Suckler Herd

In the past 12 months, what were the average number of suckler cows on your farm? *

What is your calving pattern? (Tick all that apply) *

- ☐ Spring
- ☐ Autumn
- ☐ All Year Round

What percentage of your calf crop are sold as follows: *

	%
Weaned calves (less than 1 year old)	
Store cattle (greater than 1 year old)	
Finished Cattle	
Retained for breeding	

What is your target age for finished cattle from your suckler herd? *

Calf Rearing

How many dairy calves on milk have you purchased in the past 12 months? *

What percentage of your purchased calves are sold as follows: *

	%
Weaned Calves (less than 1 year old)	
Store Cattle (greater than 1 year old)	
Finished Cattle	
Veal / Rose Veal	

If you finish them yourself, what is your target finishing age for these animals? *

Growing & Finishing Cattle

How many weaned calves (less than 1 year old) have you purchased in the past 12 months? *

How many store cattle (greater than 1 year old) have you purchased in the past 12 months? *

What percentage of your purchased weaned calves or store cattle are sold as follows: *

	%
For Finishing Elsewhere	
Finished Cattle	

If you finish them yourself, what is your target finishing age for these animals? *

Sourcing & Infectious Disease

Do you consider the following disease statuses when purchasing in cattle?

	Always	Sometimes	Never
BVD	☐	☐	☐
Leptospirosis	☐	☐	☐
IBR	☐	☐	☐
Neospora	☐	☐	☐
Johnes	☐	☐	☐

Which of the following have you tested for in the past 12 months? *

	Result
BVD	
Leptospirosis	
IBR	
Johnes	
Neospora	

	Result
Lungworm	
Fluke	

Farm Software

Do you run any farm management software? *

- [ ] Yes (please specify)
- [ ] No

Comments:

What information do you collect digitally? (tick all that apply)

- [ ] Cattle Movements
- [ ] Weights
- [ ] Body condition score
- [ ] Disease problems
- [ ] Medicine records
- [ ] Feed Usage
- [ ] Farm Finances
- [ ] Kill Information
- [ ] Other (please specify):

Cattle Health

Where do you go predominately for information and advice on the health of your cattle?

- [ ] Local vet
- [ ] Veterinary consultant
- [ ] Agricultural consultant
- [ ] Nutritionist
- [ ] Another farmer
- [ ] Sales merchant
- [ ] AHDB publication/website
- [ ] The internet/social media
- [ ] Text book/magazine

Comments:

Please rate the following health issues in terms of challenges to your herd (1= Significant health issue, 5 = not a health issue at all). Use 'N/'A' if you feel that health issue isn't relevant for your beef system. *

	Rating
Navel / Joint Ill	
Diarrhoea in calves under a month old	
Coccidiosis	
Worms	
Liver Fluke	
Pneumonia	
Lameness	
Mastitis	
Fertility	
Other (please specify)	

Comments:

Cattle Health: Pneumonia

Which antibiotic product do you most commonly use for pneumonia? *

How do you use this product?

- [ ] To treat individual sick animals
- [ ] For group treatment following outbreak
- [ ] As a preventative treatment

Which group of animals do you treat most commonly for pneumonia?

- [ ] Breeding Herd
- [ ] Pre-Weaned Calves
- [ ] Store Cattle (Less than 1 year old)
- [ ] Store Cattle (1 year old or more)

What proportion of the group selected above have you treated for pneumonia in the past 12 months?

- [ ] <5%
- [ ] 5-15%
- [ ] 15-50%
- [ ] >50%

Cattle Health: Lameness

Which antibiotic product do you most commonly use for lameness? *

How do you use this product?

- [ ] To treat individual lame animals
- [ ] For group treatment following outbreak

Which group of animals do you treat most commonly for lameness?

- [ ] Breeding Herd
- [ ] Pre-Weaned Calves
- [ ] Store Cattle (Less than 1 year old)
- [ ] Store Cattle (1 year old or more)

What proportion of the group selected above have you treated for lameness in the past 12 months?

- [ ] <5
- [ ] 5-15%
- [ ] 15-50%
- [ ] >50%

Cattle Health: Calving related disease

Which antibiotic product do you most commonly use for calving related disease e.g. difficult calvings, retained membranes or uterine infection? *

What proportion of your breeding herd have you treated for calving related disease in the past 12 months?

- [ ] <5%
- [ ] 5-15%
- [ ] 15-30%
- [ ] 30% or more

Cattle Health: Scour

Which antibiotic product do you most commonly use for scour? *

How do you use this product?

- [ ] To treat individual sick animals
- [ ] For group treatment following outbreak
- [ ] As a preventative treatment

Which group of animals do you treat most commonly for scour?

- [ ] Pre-Weaned Calves
- [ ] Store Cattle (Less than 1 year old)
- [ ] Store Cattle (1 year old or more)

What proportion of the group selected above have you treated for scour in the past 12 months?

- [ ] <5%
- [ ] 5-15%
- [ ] 15-50%
- [ ] >50%

Cattle Health: Mastitis

Which antibiotic product do you most commonly use for mastitis? *

What proportion of your breeding herd have you treated for mastitis in the past 12 months?

- [ ] <5%
- [ ] 5-15%
- [ ] 15-25%
- [ ] 25% or more

Cattle Health: Navel / Joint Ill

Which antibiotic product do you most commonly use for navel or joint ill? *

How do you use this product?

- [ ] To treat individual sick animals
- [ ] For group treatment following outbreak
- [ ] As a preventative treatment

What proportion of the group selected above have you treated for navel or joint ill in the past 12 months?

- [ ] <5%
- [ ] 5-15%
- [ ] 15-25%
- [ ] 25% or more

Cattle Health

Are you aware that some antibiotics used in farming are classed as "critically important" to human health? These are often referred to as 'CIA's'. In the UK, fluoroquinolones, 3rd and 4th generation cephalosporins and colistin are recognised as the most important of the CIA's, as designated by the European Medicines Agency. *

- [ ] Yes
- [ ] No

If yes, please list the names of any critically important antibiotics you are aware of:

Which of the following statements do you agree with the most: Antibiotic usage on my beef herd (per head) *

- [ ] Is roughly the same as it was three years ago
- [ ] Has reduced over the last three years
- [ ] Has increased over the last three years

Comments:

Which of the following statements do you agree with the most: I believe the use of antibiotics (per head) in my beef herd will *

- [ ] Remain roughly the same over the next three years
- [ ] Reduce over the next three years
- [ ] Increase over the next three years

Comments:

Which of the following statements do you agree with the most: I think antibiotic use in my herd is *

- [ ] Less than other similar beef enterprises
- [ ] Approximately the same as other similar beef enterprises
- [ ] Higher than other similar beef enterprises

Comments:

Farmer Opinions

Antibiotics: How much do you agree with the following statements? (1 = Strongly Agree, 5 = Strongly Disagree) *

	1	2	3	4	5	Don't know
Use of antibiotics is beneficial to prevent diseases in my herd.	☐	☐	☐	☐	☐	☐
Use of antibiotics is beneficial to maximise	☐	☐	☐	☐	☐	☐

	1	2	3	4	5	Don't know
productivity of my herd.						
Use of antibiotics is beneficial to the welfare of my herd.	☐	☐	☐	☐	☐	☐
It is ok to use antibiotics to treat sick individual animals.	☐	☐	☐	☐	☐	☐
It is ok to use antibiotics to prevent disease in animals.	☐	☐	☐	☐	☐	☐
Society thinks farmers use too much antibiotics	☐	☐	☐	☐	☐	☐
Using less antibiotics makes me a good farmer.	☐	☐	☐	☐	☐	☐

I have heard about antibiotic resistance in the last year from the following sources (tick all that apply) *

- ☐ National authorities or international organisations
- ☐ Print or other media
- ☐ Through discussions with my veterinary surgeon
- ☐ Retailer communications / meetings
- ☐ I haven't heard about antibiotic resistance in the past year

Antibiotic Resistance: How much do you agree with the following statements? (1 = Strongly Agree, 5 = Strongly Disagree) *

	1	2	3	4	5	Don't know
I understand what 'antibiotic resistance' means.	☐	☐	☐	☐	☐	☐
Preventative use (use in healthy animals) of antibiotics can contribute to antibiotic resistance in cattle.	☐	☐	☐	☐	☐	☐
Curative use (use in sick animals) of antibiotics can contribute to antibiotic resistance in cattle.	☐	☐	☐	☐	☐	☐
The use of antibiotics in animals can contribute to antibiotic resistance in people.	☐	☐	☐	☐	☐	☐

Reducing Antibiotic Use: How much do you agree with the following statements? (1 = Strongly Agree, 5 = Strongly Disagree) *

	1	2	3	4	5	Don't know
Reduction in the use of antibiotic could be achieved with better management or vaccination.	☐	☐	☐	☐	☐	☐
Eradicating bovine viral diarrhoea (BVD) will reduce antibiotic use.	☐	☐	☐	☐	☐	☐
There is pressure to reduce use of injections such as Metacam, Finadyne, Ketofen and Rimadyl?	☐	☐	☐	☐	☐	☐
If every beef farmer followed best practice, there would be less bacteria resistant to antibiotics in the human population.	☐	☐	☐	☐	☐	☐
I have the skills and knowledge needed to reduce antibiotics use in my herd in the near future.	☐	☐	☐	☐	☐	☐
Reducing the use of antibiotics in my herd over the next year would be difficult to achieve.	☐	☐	☐	☐	☐	☐
Reducing antibiotic usage in my herd would have costs.	☐	☐	☐	☐	☐	☐

Producer Opinions

What do you feel is the biggest benefit to reducing antibiotic use on your farm? *

- ☐ Improved consumer confidence
- ☐ Improved animal performance through better health
- ☐ Alleviation of supermarket concerns
- ☐ Reduced antibiotic resistance in humans
- ☐ Reduced antibiotic resistance in animals
- ☐ Avoidance of government intervention
- ☐ Don't know

Do you feel you have the support you need to reduce antibiotic use on your beef enterprise? *

- [ ] Yes
- [ ] No
- [ ] Not Sure

What additional support do you think would be helpful to help reduce antibiotic use in your beef herd? (tick all that apply)

- [ ] More information on disease control
- [ ] One-to-one advice on reducing disease in my herd
- [ ] Clearer messages about goals in antibiotic use
- [ ] More information on different types of antibiotic
- [ ] Benchmarking data on antibiotic use in beef enterprises
- [ ] Other (please specify):

Appendix 7: Benjamini-Hochberg corrected p-values with a false discovery rate of 0.1 for the exploratory univariable logistical regression for Study 4

Variables	P-values	Benjamini-Hochberg significance	Benjamini-Hochberg P-value
Main treatment group calves	<0.001	significant	<0.001
Calf rearing enterprise	<0.001	significant	<0.001
Pneumonia significant health problem	<0.001	significant	<0.001
Consider Johne's disease	0.008	significant	0.038
Weigh on arrival	0.010	significant	0.038
AMU less than others	0.013	significant	0.041
Record disease events digitally	0.025	significant	0.067
Record movements digitally	0.028	significant	0.067
Advice from an external consultant	0.035	significant	0.068
Mechanical ventilation employed	0.036	significant	0.068
Has dairy enterprise	0.089	not significant	0.153
Has support to reduce AMU	0.152	not significant	0.241
Take action against lungworm	0.193	not significant	0.282
Age of farmer	0.307	not significant	0.417
AMU will reduce in next 3 years	0.56	not significant	0.703
Has sheep enterprise	0.601	not significant	0.703
Aware of CIAs	0.629	not significant	0.703
Vet is main source of advice	0.786	not significant	0.830
Not sure if have support to reduce AMU	0.918	not significant	0.918

Appendix 8: Survey for Study 5

Sheep farming survey 2017

Thank you very much for participating in this survey. We really appreciate the time and effort that you will put in to completing it.

The total information gathered will be useful to Sainsbury's, as they aim to understand more about their lamb supply chain and how to better support suppliers such as yourself. Sainsbury's will use the aggregated data to share insights with the processors and producer groups. The results as a whole, will be invaluable in Sainsbury's public relation activity – whether in their promotion of the lamb industry to consumers or in its defence when engaging with pressure groups.

The data collected will be fed into a PhD at the University of Nottingham which aims to understand main factors influencing productivity and health in sheep farms and will feed back results both to Sainsbury's and more widely for the benefit of the sheep industry.

Ultimately, we aim for the results to be of direct benefit to you and your business as you consider your sheep farming enterprise within the context of the aggregated results.

This survey has six sections and each one should take around 10 minutes to complete. It is structured as following:

1) You and your farm
2) Feed and grassland
3) Your flock production (flock size, lambing period, lamb sales)
4) Health and performance of your flock
5) Your opinions on farming
6) Antibiotic usage and your opinions on antibiotic resistance.

In this survey, there will be some questions on figures for your farm, so it would be helpful for you to have your flock records and medicines book to hand.

I understand that the information I provide in this survey will be kept confidential by the Lamb Survey Team, who are working for J Sainsbury's, The Evidence Group (independent consultants working on behalf of J Sainsbury's) and the University of Nottingham. My information will not be shared outside this team or published in any way that can be linked to my farm business. I agree to allow Dunbia or Randell Parker Foods to confidentially share my farm address and all abattoir data for my lambs with the Lamb Survey Team for research purposes. I give permission for the anonymised and aggregated data generated from this survey to be used and published by the Lamb Survey Team on behalf of J Sainsbury's, The Evidence Group or the University of Nottingham. *

- [ ] I agree
- [ ] I don't agree

I. You and your farm

1. How long have you personally been farming sheep? (years)

Years

2. In which age category are you?

- [ ] Prefer not to say
- [ ] Under 25
- [ ] 26-35
- [ ] 36-45
- [ ] 46-55
- [ ] 56-65
- [ ] Over 65

3. What is your highest level of education?

- [ ] Secondary school
- [ ] Technical college
- [ ] University

4. Are you the primary manager of the farm?

- [ ] Yes
- [ ] No

Livestock

5. How many ewes did you have in August 2017? *

Mature ewes	
Ewe lambs / gimmers	

6. What are the main three ewe breeds/type on your farm and approximately how many ewes do you currently have in each category? *

Breed name or type	Number of ewes

7. What are the main three ram breeds/type on your farm and approximately how many rams of each breed do you currently have in each category?

Breed name or type	Number of ewes

8. Do you keep other livestock on your farm? Please indicate number of heads per livestock species present on farm in August 2017. Please insert 0 if you keep no animal of a given category.

Adult beef cows	
Adult dairy cows	
Cattle - other	
Pigs	
Poultry	
Other livestock	

9. Do you have other significant farming activities that you run alongside your livestock enterprise (e.g. arable, potatoes)?

- [ ] Yes
- [ ] No

10. Were you changing the size of your sheep flock between September 2016 and August 2017? *

- [ ] No
- [ ] Yes, increased sheep numbers
- [ ] Yes, reduced sheep numbers

11. Please indicate what you consider to be the most important product of your flock between September 2016 and August 2017.

- [ ] Breeding females
- [ ] Finished lambs
- [ ] Store lambs
- [ ] Other (please specify):

12. Please indicate what you consider to be the next most important product of your flock between September 2016 and August 2017.

- [ ] Breeding females
- [ ] Finished lambs
- [ ] Store lambs
- [ ] Other (please specify):

13. How would you describe your flock? You may tick more than one option. *

- [ ] Lowland flock that lambs inside
- [ ] Lowland flock that lambs outside
- [ ] Upland flock that lambs inside
- [ ] Upland flock that lambs outside
- [ ] Hill flock that lambs inside
- [ ] Hill flock that lambs outside
- [ ] Other (please specify):

14. What is the type of production system of your farm? *

- [ ] Conventional
- [ ] Organic
- [ ] Currently changing from conventional to organic
- [ ] Currently changing from organic to conventional

15. What is the total area that you farm (acres)? *

16. What is the total grassland area that you used for sheep from September 2016 to August 2017 (acres)? *

17. How many regular farm workers, including family members, were employed on your farm between September 2016 and August 2017? *

Full time

Part time

18. What was the average total number of people on the farm per day in the middle of 2017 lambing? *

19. What % of your working hours did you personally spend with your sheep flock from September 2016 to August 2017? *

20. Over the past 3 years has your sheep flock made a profit or loss (without considering any payment support & agri-environmental payments or taking into account the rental equivalent on owned land)? *

- [ ] Profit
- [ ] Breakeven
- [ ] Loss
- [ ] Do not know

21. Please select the option that most closely represents the proportion of your annual farm income obtained directly from the sheep flock (i.e. not including payment support or agri-environmental payments). *

- [ ] 100%
- [ ] About 75%
- [ ] About 50%
- [ ] About 25%
- [ ] Below 25%

II. Feed and grassland

22.1. Please consider the following statements and answer whether they were true for the sheep farming area of your farm between Sept 2016 and August 2017. Please answer for the relevant proportion (by ticking one of the following five options) and note that we realise that a number of statements may relate to the same piece of land. *

	Sheep area of my farm				
	None	Some (<35%)	About half (35 - 65%)	Most (>65%)	All
The land was in a NVZ area.	☐	☐	☐	☐	☐
The land was SDA/LFA (severely disadvantaged/less favoured area).	☐	☐	☐	☐	☐
The land was owned.	☐	☐	☐	☐	☐
The land was rented.	☐	☐	☐	☐	☐
The management of grassland was kept to a minimum.	☐	☐	☐	☐	☐
Farmyard manure or slurry was spread.	☐	☐	☐	☐	☐
Fertiliser was spread on the ground.	☐	☐	☐	☐	☐
Lime was spread on the ground.	☐	☐	☐	☐	☐
I knew the pH of the soil.	☐	☐	☐	☐	☐
I knew the soil indices for different fields.	☐	☐	☐	☐	☐
Soil samples were taken for analysis.	☐	☐	☐	☐	☐

22.2. Please consider the following statements and answer whether they were true for the sheep farming area of your farm between Sept 2016 and August 2017. Please answer for the relevant proportion (by ticking one of the following five options) and note that we realise that a number of statements may relate to the same piece of land. *

	Sheep area of my farm				
	None	Some (<35%)	About half (35-65%)	Most (>65%)	All
The area was permanent pasture.	☐	☐	☐	☐	☐
The grass was reseeded.	☐	☐	☐	☐	☐
Forage crops were grown for sheep.	☐	☐	☐	☐	☐
Grass was cut to make silage/hay.	☐	☐	☐	☐	☐
Root crops were grown for the sheep.	☐	☐	☐	☐	☐
The sheep were set-stocked.	☐	☐	☐	☐	☐
The sheep were rotationally grazed.	☐	☐	☐	☐	☐
Sheep were grazed on land that is part of an arable rotation.	☐	☐	☐	☐	☐
Sheep were kept on land from which a vegetable crop had been harvested.	☐	☐	☐	☐	☐
Sheep were stocked less than 6 sheep/acre.	☐	☐	☐	☐	☐
Sheep were stocked more than 6 sheep/acre.	☐	☐	☐	☐	☐
Sheep were co-grazed with cattle.	☐	☐	☐	☐	☐
Grass growth was monitored using a sward stick or plate meter.	☐	☐	☐	☐	☐
Grass growth was monitored by eye.	☐	☐	☐	☐	☐
Pasture was identified as clean with regards to worm contamination.	☐	☐	☐	☐	☐

23. What was the main source of feeding (>50% of time) of your adult sheep during the periods specified below? *

	Pasture with no supplement of other feedstuff/concentrates	**Pasture with supplement** of feedstuff/ concentrates as necessary	**Sheep were kept inside** with no access to pasture
Around tupping 2016	☐	☐	☐
Mid pregnancy 2016/2017	☐	☐	☐
Late pregnancy 2016/2017	☐	☐	☐
Ewes with lambs at foot 2017	☐	☐	☐

24. Please indicate type of feed fed to lambs born in 2017 (autumn 2016 tupping). *

	Grass only	Grass supplemented with restricted amount of creep	Grass supplemented with creep ad libitum (i.e. amount not restricted)	No lambs were kept on farm this time
January 2017	☐	☐	☐	☐
February 2017	☐	☐	☐	☐
March 2017	☐	☐	☐	☐
April 2017	☐	☐	☐	☐
May 2017	☐	☐	☐	☐
June 2017	☐	☐	☐	☐
July 2017	☐	☐	☐	☐
August 2017	☐	☐	☐	☐

III. Your flock production

To understand your flock production, we would like to ask you questions on several topics that affect it, such as practices at lambing, body condition scoring, culling and other management practices.

25. Did you lamb all your ewes together or did you have several lambing groups?

- [ ] Several lambing groups (please go to **question 26**)
- [ ] Whole flock together (please go to **question 32**)

26. Please provide the following information for each lambing group, filling in the columns corresponding to the number of lambing groups you had. If you cannot give an accurate answer then please complete box as "q". *

	Group 1	Group 2	Group 3	Group 4
What was the reason for grouping these ewes? (age, breed, time of lambing,...)				
How many ewes went to the ram (in total)?				
How many mature ewes were present in this group?				
How many ewe lambs were present in this group?				

26.1. The information provided came from... *

- [ ] Records
- [ ] Memory

27. Do you have scanning figures for these groups? *

- [ ] Yes (please go to question 28)
- [ ] No (please go to question 29)

28. If yes, please provide more information about your lambing groups. If you cannot give an accurate answer then please complete box as "q". *

	Group 1	Group 2	Group 3	Group 4
How many ewes (mature and ewe lambs) carrying a single?				
How many ewes (mature and ewe lambs) carrying twins?				
How many ewes (mature and ewe lambs) carrying triplets or more?				
How many empty ewes at scanning?				
How many ewes, scanned in lamb, failed to lamb or aborted before lambing?				

28.1. The information provided came from... *

- [ ] Records
- [ ] Memory

29. What were the start and end dates of 2017 lambing? *

	Group 1	Group 2	Group 3	Group 4
When did the lambing period of this group start?				
When did the lambing period of this group finish?				

30. Please indicate per lambing group the following information. Please insert "q " if you cannot provide an accurate answer. *

	Group 1	Group 2	Group 3	Group 4
How many lambs did you sell before weaning?				
What was the age of weaning for the group (weeks)?				
What was the average lamb weight at weaning (kg)?				

31. Do you know how many lambs were born dead or died at lambing? If yes, please tell us how many lambs died the comment box. *

- [ ] Yes, I know how many lambs were born dead or died at lambing because I kept records of lamb mortality
- [ ] Yes, I can provide an estimate based on memory of how many lambs were born dead or died at lambing
- [ ] No, it is hard to say how many lambs were born dead or died at lambing

31.1. Number of lambs born dead/died at lambing

Whole flock lambing

32. Please provide the following information for the whole flock, filling in the columns below. If you cannot give an accurate answer then please complete box as "q". *

	Whole flock
How many ewes went to the ram (in total)?	
How many mature ewes were present in the flock?	
How many ewe lambs were present in the flock?	

33. Do you have scanning figures of the whole flock? *

- ☐ Yes (if yes please go to question 34)
- ☐ No (if yes please go to question 35)

34. Please tell us about number of ewes carrying triplets, twins and singles after tupping 2016. If you cannot give an accurate answer then please complete box as "q". *

	Whole flock
How many ewes (mature and ewe lambs) were carrying a single lamb?	
How many ewes (mature and ewe lambs) were carrying **twins**?	
How many ewes (mature and ewe lambs) were carrying **triplets or more?**	
How many were **empty ewes at scanning?**	
How many ewes, **scanned in lamb, failed to lamb or aborted before lambing?**	

35. What were the start and end dates of 2017 lambing? *

	Whole flock
When did the lambing period start?	
When did the lambing period finish?	

36. Below there are questions on weaning age and weaning weight. If you cannot give an accurate answer then please complete box as "q". *

What was the age of weaning of 2017 lambs (weeks)?

What was the average lamb weight at weaning of 2017 lambs (kg)?

37. Do you know how many lambs were born dead or died at lambing? If yes, please tell us how many lambs died the comment box. *

- [ ] Yes, I know how many lambs were born dead or died at lambing because I kept records of lamb mortality
- [ ] Yes, I can provide an estimate based on memory of how many lambs were born dead or died at lambing
- [ ] No, it is hard to say how many lambs were born dead or died at lambing

37.1. Number of lambs born dead/died at lambing

38. Please tell us the time that you had an accurate count of 2017 lambs: *

- [ ] at birth
- [ ] within 2 days of birth
- [ ] within a week of birth
- [ ] within a month of birth
- [ ] within two months of birth
- [ ] I did not count my lambs at lambing time

39. How many lambs did you have at the time period selected in the previous question? If you cannot give an accurate answer then please complete box as "q". *

40. How many lambs did you have at weaning? If you cannot give an accurate answer then please complete box as "q". *

Body condition scoring

41. Did you physically put your hands in the back of individual ewes to assess their body condition score between September 2016 and August 2017? *

- [ ] Yes (please go to question 42)
- [ ] No (please go to question 43)

42. If yes, in which production phase(s) did you do body condition scoring (by physically putting your hands in the back of individual ewes) and how many ewes did you assess by this method? *

	None (0%)	Few ewes (>10%)	Some ewes (10-50%)	Majority of ewes (50-90%)	Most ewes (>90%)
4 weeks before mating	☐	☐	☐	☐	☐
At mating	☐	☐	☐	☐	☐
First half of pregnancy	☐	☐	☐	☐	☐
Second half of pregnancy	☐	☐	☐	☐	☐
Early lactation	☐	☐	☐	☐	☐
At weaning	☐	☐	☐	☐	☐

43. Which of these characteristics was/were more important when selecting bought in replacement ewes from September 2016 to August 2017? You may select more than one option. *

- [ ] Visual appearance/conformation/Breed
- [ ] Health status of flock of origin
- [ ] Factors not related to ewes (e.g. cost, proximity, availability, ...)
- [ ] Did not buy replacement ewes from Sep 2016 to Aug 2017

44. Which of these characteristics was/were more important when selecting bought in replacement rams from September 2016 to August 2017? You may select more than one option. *

- [ ] Visual appearance/conformation/Breed
- [ ] Estimated breeding values (EBV)
- [ ] Factors not related to ewes (e.g. cost, proximity, availability, ...)
- [ ] I would select on EBVs but they are not available for the sheep I am buying
- [ ] Did not buy replacement rams from Sep 2016 to Aug 2017

45. Which of these characteristics was/were more important when selecting home bred replacement ewes from September 2016 to August 2017? You may select more than one option. *

- [ ] No active selection
- [ ] Appearance
- [ ] Body condition score
- [ ] Recorded performance (i.e. weights)
- [ ] Fertility of mother as recorded by EID
- [ ] Fertility of mother as recorded by other methods (i.e. ear notch, lambing group)
- [ ] Mothering ability of mother as recorded by EID
- [ ] Mothering ability of mother as recorded by other methods
- [ ] Number of lameness events in the mother
- [ ] Other

Store lambs purchased

46. Did you buy in store lambs from September 2016 to August 2017? *

- [ ] Yes (please go to question 47)
- [ ] No (please go to question 48)

47. How many store lambs did you purchase per month from September 2016 to September 2017? The columns below have default 0 which you can delete to insert your estimates.

September 2016	
October 2016	
November 2016	
December 2016	
January 2017	
February 2017	
March 2017	
April 2017	
May 2017	
June 2017	
July 2017	
August 2017	

47.1. The information provided came from...

- [ ] Memory
- [ ] Records

Lamb sales

48. Thinking about lambs born in 2017, what factor had a strongest influence in your decision to sell your lambs to the abattoir? *

- [ ] Lamb weight
- [ ] Market prices
- [ ] Carcass finish
- [ ] Grass/feed availability
- [ ] Time of the year
- [ ] Other (please specify):

49. Did you sell lambs to Dunbia Llanybydder from January to August 2017? *

- [ ] Yes (please go to question 49.1)
- [ ] No (please go to question 50)

49.1. Do you give us permission to access this data directly from the abattoir? *

- [ ] Yes (please go to question 50)
- [ ] No (please go to question 49.2)

49.2. Please indicate, per month, total number of lambs sold deadweight to Dunbia Llanybydder. *

January 2017
February 2017
March 2017
April 2017
May 2017
June 2017
July 2017

August 2017

50. Did you sell lambs to Randell Parker Foods from January to August 2017? *

- [ ] Yes (please go to question 50.1)
- [ ] No (please go to question 51)

50.1. Do you give us permission to access this data directly from the abattoir? *

- [ ] Yes (please go to question 52.1)
- [ ] No (please go to question 50.2)

50.2. Please indicate, per month, total number of lambs sold deadweight to Randell Parker Foods. *

January 2017
February 2017
March 2017
April 2017
May 2017
June 2017
July 2017
August 2017

51. Did you sell deadweight lambs elsewhere from January to August 2017? [Please note that this information will be kept confidential and will not be shared with your main processor.] *

- [ ] Yes (please go to question 47)
- [ ] No (please go to question 48)

51.1. Please indicate, per month, total number of lambs sold elsewhere.

January 2017	
February 2017	
March 2017	
April 2017	
May 2017	
June 2017	
July 2017	
August 2017	

52. Did you sell lambs as stores from January to August 2017? *

- [ ] Yes (please go to question 52.1)
- [ ] No (please go to question 53)

52.1 Please indicate, per month, total number of store lambs sold. The columns below have default 0 which you can delete to insert your figures. *

January 2017	
February 2017	
March 2017	
April 2017	
May 2017	
June 2017	
July 2017	
August 2017	

52.2. The information provided on lamb sales came from... *

- [ ] Records
- [ ] Memory

53. How many lambs born in 2017 do you intend to keep and/or sell for breeding? Please insert "q" if you cannot provide an accurate answer. *

Number of lambs	Intend to keep for breeding	Intend to sell for breeding

54. How many sheep came onto or left the farm between September 2016 and August 2017 in the following categories? *

	Number of ewes
Purchased	
Sold for breeding	
Sold for Cull	
Died on farm	

54.1. The information provided came from... *

- [ ] Records
- [ ] Memory

55. Can you estimate how many lambs you plan to sell to Dunbia Llanybydder from September 2017 to April 2018?

Sep 2017	
Oct 2017	
Nov 2017	
Dec 2017	
Jan 2018	
Feb 2018	
Mar 2018	
Apr 2018	

56. Can you estimate how many lambs you plan to sell to Randell Parker Foods from September 2017 to April 2018?

Sep 2017	
Oct 2017	
Nov 2017	
Dec 2017	
Jan 2018	
Feb 2018	
Mar 2018	
Apr 2018	

57. Can you estimate how many lambs (intended for meat) that you plan to sell elsewhere from September 2017- April 2018? The columns below have default 0 which you can delete to insert your estimates.

Sep 2017	
Oct 2017	
Nov 2017	
Dec 2017	
Jan 2018	
Feb 2018	
Mar 2018	
Apr 2018	

IV. Health and performance of your flock

The way you answer this question will help us interpret your other answers so please select the options that you think are true:

58. Comparing to other similar farmers, you believe your flock has... *

- [ ] Better health
- [ ] Similar health
- [ ] Poorer health

59. Comparing to other similar farmers, you believe your flock has... *

- [ ] Better productivity
- [ ] Similar productivity
- [ ] Poorer productivity

60. We would like to know more about health problems affecting your flock between September 2016 and August 2017. Please tick the options that best reflect the situation at your farm. You can tick as many boxes as you like for each disease. *

	I routinely took action to control this disease in my flock	I was particularly concerned about this disease in my flock	I think this disease caused production issues in my flock	I was not concerned about this disease in my flock
Coccidiosis	☐	☐	☐	☐
Scab	☐	☐	☐	☐
Liver fluke	☐	☐	☐	☐
Gut worms	☐	☐	☐	☐
Haemonchus	☐	☐	☐	☐
Clostridial disease	☐	☐	☐	☐

61. Approximately how many ewes were affected by each disease from September 2016 to August 2017? *

Mastitis	
Lameness	
Twin lamb disease	
Lambing difficulties	
Prolapses	
Other (please specify below)	

Other disease:

62. Approximately how many baby lambs were affected by each disease from September 2016 to August 2017? *

	Number of ewes
Watery mouth	
Joint ill	
Scour	
Other (please specify)	

63. Did you vaccinate any of your sheep with Footvax between September 2016 and August 2017? *

- [ ] No
- [ ] Yes, all ewes
- [ ] Yes, some of the ewes
- [ ] Yes, rams
- [ ] Other (please specify): _____

64. On average, how soon did you treat individual lame sheep after seeing that it was lame between September 2016 and August 2017? *

- [ ] The first day you saw it
- [ ] Within three days
- [ ] Within one week
- [ ] Within two weeks
- [ ] Longer than two weeks

65. Please complete the table below to tell us about your treatment of individual lame sheep between September 2016 and August 2017. *

	Always	Usually	Sometimes	Never
Did you trim diseased feet?	☐	☐	☐	☐
Did you use antibiotic injection?	☐	☐	☐	☐
Did you use a foot spray?	☐	☐	☐	☐
Did you separate lame sheep from the rest of the flock?	☐	☐	☐	☐

66. Which type of ewes did you treat for worms around 2017 lambing time? You may tick more than one option. *

- [ ] I did not treat ewes for worms around lambing time
- [ ] Whole flock
- [ ] Mature ewes
- [ ] Ewe lambs
- [ ] Thin ewes
- [ ] Some ewes, based on the number of lambs they were carrying
- [ ] Other (please specify): _____

67. What information did you mainly use to prompt you to worm lambs from lambing to August 2017? *

- [ ] I did not treat lambs for worms
- [ ] A date
- [ ] Visual assessment of flock
- [ ] Weight gains
- [ ] FEC (faecal egg counting)
- [ ] Other (please specify): _____

68. Did you use faecal egg counting last year from September 2016 to August 2017? *

- [ ] No
- [ ] Yes, up to 3 times per year
- [ ] Yes, 4-11 times per year
- [ ] More than 12 times per year

69. What were the 3 most common reasons for selecting ewes for culling from September 2016 to August 2017? Please select 3 options from the list below. *

- [ ] Mastitis
- [ ] Lameness
- [ ] Tooth loss
- [ ] Poor Condition
- [ ] Old Age
- [ ] Infertility
- [ ] Low Productivity
- [ ] Prolapse
- [ ] Other (please specify): _____

70. What method(s) did you use to record information on farm from September 2016 to August 2017? You may tick more than one option. *

- [ ] Any piece of paper
- [ ] Notebook/Diary
- [ ] EID handheld
- [ ] Smartphone
- [ ] Computer
- [ ] Tablet
- [ ] Other (please specify): _____

71. Could you tell us more about what you have recorded from September 2016 to August 2017? *

	I have not recorded this information for any animal	I recorded this information for some animals	I recorded this information for all animals
Individual records of lame ewes	☐	☐	☐
Individual records of aborted ewes	☐	☐	☐
Individual records of animals treated with antibiotics	☐	☐	☐
Ewe mothering abilities	☐	☐	☐
Lamb weights at 6-8 weeks of age	☐	☐	☐
Lambs weights at weaning	☐	☐	☐
Lamb weights between weaning and sales	☐	☐	☐

72. Please select which pieces of information you actually used to manage flock performance from September 2016 to August 2017. You may tick more than one option. *

- [ ] I do not use specific data, I rely on my experience and intuition
- [ ] Lamb mortality data
- [ ] Abattoir data
- [ ] Recorded growth rates from weighing lambs
- [ ] Body condition score information
- [ ] Scanning %
- [ ] EID recorded information
- [ ] Other (please specify): _____

73. Have you changed any management practices in the past 3 years? You may tick more than one option. If yes, please tell us what you did differently in the comment box. *

- [ ] No, I haven't changed any management practices
- [ ] Yes, I have changed my culling practices
- [ ] Yes, I have changed my recording practices
- [ ] Yes, I have changed worming practices

Main changes in management practices during past 3 years:

74. How many times did you seek advice about the flock with a vet, a farmer's merchant, technical advisor/consultant or a feed representative/ nutritionist? Please indicate number

29

of contacts by telephone or during farm visits between September 2016 and August 2017 in the table below. Please insert 0 if you had no contact with any of these flock health advice providers. *

	Vet	Technical advisor/consultant	Feed representative/ nutritionist	Farmers merchant
By telephone				
At your farm				

V. Your opinions on farming business

We would like to ask your views on farming business, and on sheep farming in general.

Some questions may sound a bit odd and difficult to answer, but they are important for us to understand your views on sheep farming. We will use all questions together to form a profile, so it does not matter how you reply to a single one, but to the whole lot. The combination of your answers will help us understanding your attitudes to farming.

75. Please rank each of the statements below, selecting the option that best reflects how much you agree with each statement. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
I have a vision how to develop the farm in the long run.	☐	☐	☐	☐	☐
I follow business principles in managing my farm.	☐	☐	☐	☐	☐
A farmer today can be regarded as a business manager.	☐	☐	☐	☐	☐
My managerial skills are good.	☐	☐	☐	☐	☐
Farming in UK does not pay.	☐	☐	☐	☐	☐
I can describe my business plan easily with few sentences.	☐	☐	☐	☐	☐
A farm should be managed like any other business.	☐	☐	☐	☐	☐
It is difficult to set goals for a period of a couple of years.	☐	☐	☐	☐	☐
I have plans for investments on machinery, buildings or grassland.	☐	☐	☐	☐	☐
Young people should be encouraged to a farming career.	☐	☐	☐	☐	☐
It is rewarding to be a farmer.	☐	☐	☐	☐	☐

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
It is within my control whether or not my farm will be successful in the long term.	☐	☐	☐	☐	☐
A farmer can be proud of his/her job.	☐	☐	☐	☐	☐
I plan ahead to ensure my goals are achieved, and often do budgets and commit my ideas to paper.	☐	☐	☐	☐	☐
When things go wrong I do not handle the situation as well as I could do.	☐	☐	☐	☐	☐
I find it easy to ring up strangers to find out technical information.	☐	☐	☐	☐	☐
I normally do not rest until the job is fully completed.	☐	☐	☐	☐	☐
I tend to mull over decisions before acting.	☐	☐	☐	☐	☐
My farm is completely oriented towards maximizing productivity.	☐	☐	☐	☐	☐
It is very important to stick to management principles no matter what the pressure to do otherwise.	☐	☐	☐	☐	☐
I usually find discussing everything with members of my family and/or colleagues very helpful.	☐	☐	☐	☐	☐
I am much happier if everything is planned well ahead of time.	☐	☐	☐	☐	☐
Keeping records on just about everything is very important.	☐	☐	☐	☐	☐
Poor results are usually due to things completely out of my control.	☐	☐	☐	☐	☐
I tend to seek the views of many people before making changes to my operations.	☐	☐	☐	☐	☐

VI. Antibiotic usage and your opinions on antibiotic resistance

Antibiotic usage - lambs

Below there are some examples of antibiotics.



Spectam (Spectinomycin), Orojet (Neomycin Sulfate), Alamycin LA (Oxytetracycline), Engemycin (Oxytetracycline), Terramycin (Oxytetracycline) , Pen&Strep (Penicillin and Streptomycin) , Betamox LA (Amoxicillin), Oxytetracycline, Amoxypen LA (Amoxicillin), antibiotic tablets

76. Did you give any lambs any antibiotics (either those shown in the pictures or others) between September 2016 and August 2017? *

- ☐ Yes (please go to question 76.1)
- ☐ No (please go to question 77)

76.1 Could you tell us which product(s) you used to treat lambs between September 2016 and August 2017? *

	Antibiotic name
Product A	
Product B	
Product C	
Product D	
Product E	

76.2. Which proportion of lambs did you treat? *

	Few (0-25%)	Some (25 - 50%)	Many (50 - 75%)	Most (75 - 100%)	N/A
Product A	☐	☐	☐	☐	☐
Product B	☐	☐	☐	☐	☐
Product C	☐	☐	☐	☐	☐
Product D	☐	☐	☐	☐	☐
Product E	☐	☐	☐	☐	☐

76.3. How old were lambs when you treated them? *

	0- 1 week old	1 week - 1 month	1 – 4 months	> 4 months	N/A
Product A	☐	☐	☐	☐	☐
Product B	☐	☐	☐	☐	☐
Product C	☐	☐	☐	☐	☐
Product D	☐	☐	☐	☐	☐
Product E	☐	☐	☐	☐	☐

76.4. Why was the treatment necessary? *

	to prevent disease	to cure disease	N/A
Product A	☐	☐	☐
Product B	☐	☐	☐
Product C	☐	☐	☐
Product D	☐	☐	☐
Product E	☐	☐	☐

76.5. What is the origin of this information? *

	Memory	Medicines Book	Other records	N/A
Product A	☐	☐	☐	☐
Product B	☐	☐	☐	☐
Product C	☐	☐	☐	☐
Product D	☐	☐	☐	☐
Product E	☐	☐	☐	☐

Antibiotic usage – adult ewes

77. Did you give any antibiotics to any adult ewes (either those shown in the pictures or others) from September 2016 to August 2017? *

☐ Yes (please go to question 77.1)
☐ No (please go to question 78)

77.1. Which antibiotics did you use to treat ewes from September 2016 to August 2017? *

	Antibiotic name
Product A	
Product B	
Product C	
Product D	
Product E	

77.2. Which proportion of ewes did you treat with these products? *

	Few (0 -25%)	Some (25 - 50%)	Many (>50%-75)	Most (75-100%)	N/A
Product A	☐	☐	☐	☐	☐
Product B	☐	☐	☐	☐	☐
Product C	☐	☐	☐	☐	☐
Product D	☐	☐	☐	☐	☐
Product E	☐	☐	☐	☐	☐

77.3. When did you treat ewes with these products? *

	Pregnant ewes (between tupping and lambing)	At lambing time	Ewes with lambs at foot (between lambing and weaning)	Dry ewes (between weaning and tupping)	N/A
Product A	☐	☐	☐	☐	☐
Product B	☐	☐	☐	☐	☐
Product C	☐	☐	☐	☐	☐
Product D	☐	☐	☐	☐	☐
Product E	☐	☐	☐	☐	☐

77.4. Why was this treatment necessary? *

	To prevent disease	To cure disease	N/A
Product A	☐	☐	☐
Product B	☐	☐	☐
Product C	☐	☐	☐
Product D	☐	☐	☐
Product E	☐	☐	☐

77.5. This information comes from... *

- [ ] Memory
- [ ] Medicines book
- [ ] Other records

Your opinions on antibiotic usage

78. For each statement, please select the option that best reflects your opinions on antibiotic usage and antibiotic resistance. *

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
The use of antibiotics is beneficial to prevent diseases in my flock.	☐	☐	☐	☐	☐
The use of antibiotics is beneficial to ensure productivity of my flock.	☐	☐	☐	☐	☐
The use of antibiotics is beneficial to the welfare of my flock.	☐	☐	☐	☐	☐
Dosing new born lambs with an oral antibiotic is the only way to be sure watery mouth is prevented.	☐	☐	☐	☐	☐
It is ok to use antibiotics to treat sick individual animals.	☐	☐	☐	☐	☐
It is ok to use antibiotics to prevent disease in animals.	☐	☐	☐	☐	☐
Society thinks sheep farmers use too much or too many antibiotics.	☐	☐	☐	☐	☐
Society thinks all farmers use too much or too many antibiotics.	☐	☐	☐	☐	☐
The media provide a negative view on farmers regarding the use of antibiotics.	☐	☐	☐	☐	☐
Using less antibiotics makes me a good farmer.	☐	☐	☐	☐	☐
I understand what 'antibiotic resistance' means.	☐	☐	☐	☐	☐

	Strongly Disagree	Disagree	Neutral	Agree	Strongly Agree
Preventative use (use in healthy animals) of antibiotics can contribute to antibiotic resistance in sheep.	☐	☐	☐	☐	☐
Curative use (use in sick animals) of antibiotics can contribute to antibiotic resistance in sheep.	☐	☐	☐	☐	☐
The use of antibiotics in animals can contribute to antibiotic resistance in people.	☐	☐	☐	☐	☐
Reduction in the use of antibiotics could be achieved with better management or vaccination.	☐	☐	☐	☐	☐
Alternatives to antibiotics are not practical to implement.	☐	☐	☐	☐	☐
Preventative use (i.e. use in healthy animals) of antibiotics in my sheep flock helps me meet production goals.	☐	☐	☐	☐	☐
If every sheep farmer followed best practice, there would be less bacteria resistance to antibiotics in the human population.	☐	☐	☐	☐	☐
People I respect in the industry would approve of reducing the use of antibiotics in my flock over the next year.	☐	☐	☐	☐	☐
I have the skills and knowledge needed to reduce antibiotics use in my flock in a near future.	☐	☐	☐	☐	☐
Reducing the use of antibiotics in my sheep flock over the next year would be difficult to achieve.	☐	☐	☐	☐	☐
Reducing antibiotic usage in my flock would have costs.	☐	☐	☐	☐	☐

79. Comparing to your usual antibiotic usage, your usage between September 2016 and August 2017 was... *

- [ ] Roughly the same
- [ ] Lower than usual
- [ ] Higher than usual

80. I think antibiotic the use on my farm is... *

- [ ] Less than other sheep farms
- [ ] Approximately the same as other sheep farms
- [ ] Higher than other sheep farms

81. Have you talked with your vet about antibiotic usage and/or antibiotic resistance in the past year? *

- [ ] Yes, I have talked with my vet about antibiotic usage
- [ ] Yes, I have talked with my vet about antibiotic resistance
- [ ] No

82. You will appreciate that understanding more about the actual antibiotic usage within the agricultural sector is becoming more and more important as we aim to preserve medicines for the future. With this in mind we are contributing to further research in this area, with benefits to the whole supply chain, including your family as well as those who buy your lamb. We would very much like to work with you on this if you are willing. With this in mind we would like to know exactly how much antibiotic you used for the sheep in the period between September 2016 and August 2017. Please indicate how you would be able to tell us that information. *

- [ ] I can tell you exactly how much antibiotic was given to the sheep
- [ ] I can tell you how much combined antibiotic was used for the sheep and cattle
- [ ] I am not able to tell you how much antibiotic was used on my farm
- [ ] I am happy for you to contact my vet to find out how much antibiotic I purchased & I give permission for them to tell you (please go to question 82.1)
- [ ] I do not want to tell you how much antibiotic I used

82.1. Please let us know the contact details of your vet

Name	
Practice	
Phone number	
Email	

End of the survey

Thank you very much for your collaboration

Appendix 9: P-values for univariable logistic regression analysis for study 5 with Benjamini-Hochberg corrected p-values based on a false discovery rate of 0.1

Variable	P-value	Benjamini-Hochberg significance	Benjamini-Hochberg P-value
Use antimicrobials for prevention in all lambs	<0.001	significant	<0.001
Always trim feet for past 3 years	<0.001	significant	<0.001
My antimicrobial use is the same as others	<0.001	significant	<0.001
Worm lambs depending of faecal egg count	<0.001	significant	<0.001
Changed worming practice in past 3 years	<0.001	significant	<0.001
Use antimicrobials for prevention in all ewes	0.002	significant	0.009
Use a computer to record information	0.003	significant	0.012
Body condition score at mating	0.030	significant	0.100
Body condition score at weaning	0.037	significant	0.100
Sheep enterprise made a loss	0.037	significant	0.100
Take action against clostridial disease	0.086	not significant	0.198
Body condition score at mid pregnancy	0.088	not significant	0.198
Footvax all ewes	0.123	not significant	0.245
Worm whole flock	0.127	not significant	0.245
Treat lameness within 3 days	0.152	not significant	0.274
Worm lambs based on visual assessment	0.213	not significant	0.359
Changed culling practices in past 3 years	0.250	not significant	0.397
Vet advice quarterly	0.283	not significant	0.424
Vet advice once	0.342	not significant	0.486
Take action against gutworms	0.362	not significant	0.489
Worm lambs based on date	0.400	not significant	0.514
Took action against scab	0.522	not significant	0.627
Took action against haemonchus worms	0.534	not significant	0.627
Took action against liver fluke	0.638	not significant	0.718
Talk to vet about antimicrobial use	0.710	not significant	0.767
Always separate lame sheep	0.816	not significant	0.847
Did not treat ewes for worms	0.958	not significant	0.958

Appendix 10: Ethics approval form for Study 6

The University of Nottingham
UNITED KINGDOM · CHINA · MALAYSIA

School of Veterinary Medicine and Science
Research Project Review form

The Research Project Review form **should be completed for all PGR and staff research projects**, irrespective of whether funding is being sought or not for the project, and should be submitted to: SV-research@nottingham.ac.uk as early as possible (in advance of any project commencing and/or prior to any funding application being made) for School review.

Submission Checklist: To facilitate review, please confirm which sections have been completed for your research project

Section	Requirement	Completed
Section 1: Research Project and Funding Details	To be completed for all projects	☒
Section 2: Clinical Research	To be completed only if the project includes the use of (non-human) clinical material or data obtained from veterinary practices	☐
Section 3: Health and Safety	To be completed for all projects	☒
Section 4: Postgraduate Research (PGR) Project and Supervisory Team Details	To be completed only if the project necessitates the appointment of a PGR student	☐
Section 5: Ethical Considerations	To be completed for all projects	☒

Supporting documentation (as relevant)	Attached
Clinical protocols (eg, diagnostic, treatment)	☐
Statement of Research Ethics	☒

Section 1: Research Project and Funding Details

SVMS Lead:	Jasmeet Kaler
Principal investigator?	Yes ☒ No ☐ If No, please indicate PI (School, Institution):
Other Co-Is / collaborators (affiliation):	Fiona Lovatt
Project title:	Antibiotic use on sheep and beef farms
Is funding (external/ internal) being	Yes ☐ No ☒

V1.0, Approved 12.12.2016

sought for this project?			
Intended funder and funding scheme:	AHDB funded studentship -Charlotte Doidge		
Submission deadline:	NA	**Funding sought (approx.):**	
Details of any commitments required from the School:	(e.g. office/lab space, technician time, match-funding for Studentship / Fellowship, equipment, etc) None		
Details of any equipment requests over £10,000:			
Has this or a related project been submitted to this or another funder before?	Yes ☐ No ☒ If Yes, please provide brief details and indicate how the reviewers comments have been addressed:		
Please suggest up to 3 UoN peer-reviewers for the funding application:	1) 2) 3)		
Other peer support requested:	Grant clinic / Presentation to School / Mentorship / Other (please specify)		

Research Project Outline

Please provide a one page outline of the research project with a statement of why the work is important (novelty and timeliness), hypotheses (if any), objectives, experimental plan/methodology and techniques to be used

The aim of the study was to understand farmers' naturalistic decision- making around prophylactic antibiotic use in lambs. Data from 431 posts by 133 different forum users of an publicly available online discussion forum were analysed quantitatively using natural language processing and qualitatively using a grounded theory approach.

This analysis follows the guidelines set out by the British Psychological Society on internet mediated research (British Psychological Society, 2017). The forums accessed for analysis did not require registration to view forum posts and were therefore located within the public domain. Forum users were instructed not to post any private or confidential information upon registering an account Those that posted on the forum appeared aware that members of the public (not just farmers) could readily view their posts. As the posts were publicly available and did not contain private information, no steps to gain informed consent from those posting were taken. To ensure anonymity of forum users, any identifiable information about participants and forum sites was removed to maintain confidentiality (Tilley and Woodthorpe, 2011). In addition, to preserve

anonymity quotes have been paraphrased and researchers took steps in terms of checking all quotes using a search engine to ensure they cannot be traced (Roberts, 2015).

Section 2: Clinical Research

This section should be completed for all research projects that involves the use of (non-human) clinical material or data obtained from veterinary practices whether or not clinical associates: this includes cases, material or data obtained through veterinary practices or direct from owners, and seeing cases, making diagnoses or recommending treatment as part of a research project.

If the principal applicant is not MRCVS who is veterinary lead for the research team?	
Does this project involve cases beyond just those you would routinely see (i.e. collecting data from more than just your normal case load)	Yes ☐ **No ☒** If yes, please indicate how cases/material will be recruited, dealt with (eg treated) and how (if applicable) individual results will be reported to referring vets and/or owners (reference may be made to information provided in Section 1):
Does this project involve the use of School vehicles or equipment?	Yes ☐ **No ☒**
If the project involves diagnostics, treatment or advice, will fees be charged?	Yes ☐ **No ☒** If fees or subsidies are involved (or could be perceived as being involved), please describe how these will be handled:
Does the project involve Clinical Associates and/or other practices with existing formal agreements (eg MoU) with SVMS, or clients of those practices?	Yes ☐ **No ☒** If the project involves practices other than Clinical Associates, give details of practices to be involved:
If protocols are to be applied (eg particular diagnostic or treatment protocols), please attach those protocols using the format in which they will be distributed. If these are still in a draft state, the final versions may be needed before final approval is given. Include details of how Clinical Associates and School clinicians will be involved in the project	

Section 3: Health and Safety

Will this project involve the use of Drones (UAVs) for any part of the research? UoN policy and other guidance can be found at http://www.nottingham.ac.uk/safety/policies-and-guidance/drones/drones.aspx	Yes ☐ No ☒ If Yes, please ensure compliance with Civil Aviation Authority and UoN policy and that the relevant risk assessment is completed prior to initiation of the research project
Will this project involve the use of University laboratories?	Yes ☐ No ☒
Is the project covered by the appropriate risk assessment?	Yes ☐ No ☒ If No, please prepare a risk assessment prior to initiation of the research project
Does the project involve genetically modified organisms?	Yes ☐ No ☒ If Yes, please note that this may require a separate risk assessment to be prepared
If the project involves pathogens not previously used in the School, please provide details	

Section 4: Postgraduate Research (PGR) Project and Supervisory Team Details

Qualification aimed for:	PhD / MRes / DVM / MVM
Study type:	Full-time / Part-time
PGR Project Title: (if different from that given in Section 1)	
Source of funding for studentship, funding splits (if relevant), elements supported and values: eg, 50% external funder: 50% School for HEU fees, RCUK stipend and running costs of £XX pa eg, 100% Commonwealth PhD Scholarship for developing countries, OS fees at highest banding, stipend paid directly to candidate by funder	Funder(s) (% splits): Annual stipend to be paid (if relevant): £
Duration of funding for studentship:	
Proposed start date:	
Anticipated interview date:	
Student Name under consideration:	
Application already made via the Portal	Yes ☐ No ☐

Supervisory team (affiliation)	**Role**	**% credit split**	**Number of PGR students in the last 7 years who have:**		**Date last attended PGR Supervisor workshop**
			Successfully submitted within time period	**Failed, or failed to submit within time period**	
	Primary				
	Co-Supervisor				
	Co-Supervisor				
	Co-Supervisor				

Note: The primary supervisor will have day to day responsibility for the student and will be the route for communication with the post-graduate committee. The primary supervisor must have attended a post-graduate supervision workshop within the last 5 years and have completed a degree equivalent to the qualification being aimed for. The supervisory team should comprise at least two SVMS Supervisors.

Project aims: Provide brief details of aims and/or hypothesis and research questions being addressed (if these differ to that detailed in Section 1)
Methodology: Provide brief details about how the research questions will be answered (if these differ to that detailed in Section 1)

Techniques: Provide brief list of techniques the PGR student will develop. For each technique undertake a brief risk analysis (uses novel techniques, uses novel primers, tissues difficult to obtain, clinical information may be lacking – not health and safety risks) and what steps have been and will be undertaken to mitigate against those risks (alternative techniques, pilot data, agreed source of tissues)

Technique	Risk analysis	Mitigation against risks

Milestones and outputs: Provide detail of key milestones and outcomes (reports, papers etc) for this student. This will be reviewed at each annual review to confirm progression

Milestone / output	Completion date
Year 1 Review	
Year 2 Review	
Year 3 Review	
Thesis writing	

Section 5: Ethical Considerations

Please describe in a sentence or two, in this box, any details that will help the reviewers interpret the form:
There is free public online forum data we have used for analysis, We checked with Fraser Marshall around GDPR and this has been oked.

Has this or a similar research project been reviewed previously?	Yes ☒ No ☐ If Yes, please indicate previous project approval number: 1850 160916
For minor/major amendments to previously approved research projects, please outline significant changes made to the project that give rise to ethical issues and briefly indicate how these will be addressed: In the original proposal this part was not reviewed.	

Section 1. Data collection		
Q1. Does the proposed study involve obtaining information by questionnaire, interview or focus group?	Yes ☐	No ☒ Go to Q2
If yes: Have you read, understood and agree to abide with the School's policy on data collection by questionnaire, interview or focus group?* Have you attached a Statement of Research Ethics?* *Documents can be found at https://workspace.nottingham.ac.uk/display/VMaS/Research or S:\MHS\Veterinary\Research\Ethic		Yes ☒ Yes ☒
Q2. Does the proposed study involve obtaining 'owned' information through a third party – e.g. searching practice records about clinical cases?	Yes ☐	No ☒
If yes: Have you read the relevant sections of the EU General Data Protection Regulation (GDPR) and the UK Data protection act (2018) as they relate to your proposed work and, do you understand the implications of data protection and agree that the proposed study is compliant? **GDPR (UoN):** https://www.nottingham.ac.uk/governance/records-and-information-management/gdpr-overview.aspx **DPA 2018:** http://www.legislation.gov.uk/ukpga/2018/12/contents/enacted		Yes ☐

Section 2. Human material		
Q3. Does the proposed project involve human material (including primary cell lines)?	Yes ☐	No ☒ go to section 3
If yes, please provide more details about the material to be used (this information will be forwarded to Cinzia Allegrucci, HTA contact):		

Section 3. Animal material		
Q4. Does the proposed project use animals or materials obtained from them? No direct use of animals only data via video surveillance and farm management	Yes ☐ go to Q5	No ☒ go to end
Q5a. If yes to Q4, what is the source of the animals and animal derived material to be used in the proposed study (e.g. cadaver)?		
Q5b. If yes to Q4, is there a process in place for obtaining informed owner consent (forms for collecting abattoir material are available from Jes Squires /clinical technician).	Yes ☐	No ☐
Q6. Have you read and understood what types of study are regulated by ASPA, and what a regulated procedure is, by reading **the short paragraph in Section 1.1 of the** Guidance on the Operation of the Animals (Scientific Procedures) Act	Yes ☐	No ☐
Q7. Is any aspect of the proposed project to be carried out under the Animal (Scientific Procedures) Act? **If Yes, please provide Home Office Project Licence Number and protocol number.**	Yes ☐ **PPL**	No ☐ go to Q8
If **no Project Licence in place,** please consult with the Director of the BSU **or his nominee** as this must go for review to the A(SP)A University AWERB committee. Contact via this email: bsu@nottingham.ac.uk **Note:** If humane killing is to be undertaken, individuals must be appropriately trained and educated to allow them to be entered onto the University of Nottingham Register as competent to kill animals for a scientific purpose including at a POLE (**successful completion of Module K Function D**). Please contact the Named Training and Competency Officer (NTCO) for details of the training course and subsequent assessment. Contact via this email: bsu@nottingham.ac.uk		
Q8. Is any aspect of this work to be performed outside of the UK **that would otherwise be regulated under the Animals (Scientific Procedures) Act?**	Yes ☐	No ☐

If Yes, please consult with the Director of BSU or his nominee as this must go for review to the University AWERB committee.		
If the work is to be undertaken outside the UK, please state the country involved.		
Q9. Is any aspect of the proposed project to be carried out under the Veterinary Surgeon's Act (i.e. uses samples or part of samples obtained from animals using an invasive procedure, which includes surplus samples taken as part of a clinical investigation)?	Yes ☐	No ☐ go to Q10
If yes, what is the source of the animals or animal derived material to be used in the proposed study? Describe in detail the process by which samples are to be obtained – site, amount concurrent medication (e.g. sedation), restraint, clipping of fur etc.		
Is there a process in place for obtaining informed owner consent?	Yes ☐	No ☐
Q10. Does the proposed project involve modification of the behaviour or routine of any animals?	Yes ☐	No ☐ go to Q11
If yes, please describe these modifications and the potential impacts on the animals:		
Q11. Have you read and understood the ARRIVE (animal research: reporting *in vivo* experiments) guidelines at http://www.nc3rs.org.uk/page.asp?id=1357 ?		Yes ☒ N/A ☒

Declaration
I confirm that the information provided is true and complete to the best of my knowledge and the project described above complies with published codes of conduct, ethical principles and guidelines of professional bodies associated with my research discipline.

Signature of Applicant:

Jasmeet Kaler Date: 12/09/20

Approval signature (on behalf of ethical review panel):

..... Date: .....

[Office use only] Reference:	

V1.0, Approved 12.12.2016

Appendix 11: Interview schedule for Study 7

First, we will gain an understanding of how you run your farm.

1. Description of your farm and practices

-How long have you been farming for?
-How many people work on your farm?
-What animals do you keep and how many?
-What type of system do you have?
-Can you tell me about your vaccination practices?
-What are your worming practices?
Probe: Which livestock do you treat? How do you decide to treat them?
-What is the biggest problem for you on your farm?
Probe for diseases

Now, we will talk about how you use antibiotics on your farm.

Knowledge/current use

2. Where do you get your antibiotics from?

-What diseases do you usually treat with antibiotics?
-Could you describe a recent situation where you have had to use antibiotics?
Which animals do you treat? How many animals?
-What are the benefits of treating these diseases with antibiotics?
Probe: Cost, easy, safe?
-What are the drawbacks of treating with antibiotics?
Probe: Side effects
-What are the alternatives to using antibiotics for treating these diseases?
Compare the effectiveness of alternative & antibiotics
-Could you tell me some situations where it is acceptable/unacceptable to treat with antibiotics?
Probe for opinion on preventative use

Decision making

3. How do you know when an animal needs to be treated with antibiotics?

-What influences your decision to treat with antibiotics?
Probe: How does time pressure/uncertainty of diagnosis/other people you work with affect your decision?
-Do you feel confident in your ability to choose when to use antibiotics?
Do you feel confident in administering antibiotics?
-When do you find it difficult to decide on whether to administer an antimicrobial?
-What is the role of your vet in your decision to administer antibiotics?
Probe: How often are you in contact with your vet? What are the reasons for their previous visits? What did you discuss?

4. RUMA set targets for the sheep and beef sectors to reduce antimicrobial usage levels by 10% by 2020 ***(use a show card as a prop detailing the targets set out).***

-How feasible are the targets?

How would you reduce your use? /What barriers are there to reducing use?

-What are the risks associated with reducing antibiotic use on your farm?

Probe: How would reducing use affect productivity/health/costs?

-How do you feel when you decide not to give antibiotics to a sick animal?

Probe: Does this come from a particular experience?

We would like to know about your antimicrobial resistance perceptions

5. What concerns do you have regarding antibiotic resistance (AMR) on your farm?

-Have you encountered AMR problems on your farm?

If yes, describe what happened. Can you tell me what you think caused it.

-How significant is the risk of AMR to your farm?

-What are the consequences of AMR?

For your farm, for society

We would like to know your view on antimicrobial use on other farms.

6. What characteristics do you associate with a farm that uses a lot of antibiotics?

-How does your farm fit into these characteristics?

-Why do you think levels of antimicrobial use differs between farms?

-Who do you think should be responsible for monitoring antimicrobial use?

-What do you believe the consequences should be for those that use antimicrobials inappropriately?

Is there anything else regarding antibiotic use and antibiotic resistance that you would like to discuss?