

Scotland's Rural College

A quantitative analysis of attitudes and behaviours concerning sustainable parasite control practices from Scottish sheep farmers

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1 A quantitative analysis of attitudes and behaviours concerning sustainable parasite control
2 practices from Scottish sheep farmers

3

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16

17 *Keywords:* Behaviour; Parasite control; Questionnaire; S.E.M; Sheep; *Structural Equation*
18 *Modelling*

19

20

21

22 **Abstract**

23

24 Nematode control in sheep, by strategic use of anthelmintics, is threatened by the emergence

25 of roundworms populations that are resistant to one or more of the currently available drugs.

26 In response to growing concerns of Anthelmintic Resistance (AR) development in UK sheep

27 flocks, the Sustainable Control of Parasites in Sheep (SCOPS) initiative was set up in 2003 in

28 order to promote practical guidelines for producers and advisors. To facilitate the uptake of

29 ‘best practice’ approaches to nematode management, a comprehensive understanding of the

30 various factors influencing sheep farmers’ adoption of the SCOPS principles is required.

31 A telephone survey of 400 Scottish sheep farmers was conducted to elicit attitudes regarding

32 roundworm control, AR and ‘best practice’ recommendations. A quantitative statistical

33 analysis approach using structural equation modelling was chosen to test the relationships

34 between both observed and latent variables relating to general roundworm control beliefs. A

35 model framework was developed to test the influence of socio-psychological factors on the

36 uptake of sustainable (SCOPS) and known unsustainable (AR selective) roundworm control

37 practices. The analysis identified eleven factors with significant influences on the adoption of

38 SCOPS recommended practices and AR selective practices. Two models established a good

39 fit with the observed data with each model explaining 54% and 47% of the variance in

40 SCOPS and AR selective behaviours, respectively. The key influences toward the adoption of

41 best practice parasite management, as well as demonstrating negative influences on

42 employing AR selective practices were farmer’s base line understanding about roundworm

43 control and confirmation about lack of anthelmintic efficacy in a flock. The findings suggest

44 that improving farmers’ acceptance and uptake of diagnostic testing and improving

45 underlying knowledge and awareness about nematode control may influence adoption of best

46 practice behaviour.

47

48 **Introduction**

49 The sustainable control of gastro-intestinal nematode parasites remains one of the main
50 perennial endemic disease pressures that livestock farmers face globally (Jackson and Coop,
51 2000; Nieuwhof and Bishop, 2005). Gastro-intestinal nematodes impact on the health,
52 welfare and production efficiency of livestock (Coop and Kyriazakis, 2001). For over 50
53 years parasite control strategies have heavily relied on suppressing nematode populations
54 with frequent use of highly efficacious, broad spectrum anthelmintics (Bartley, 2008). The
55 effectiveness of these treatments is threatened by the emergence of nematode populations that
56 are resistant to one or more of the anthelmintic drugs available. In the UK alone, studies have
57 reported resistance to all three of the commercially available broad-spectrum anthelmintic
58 drug classes i.e. benzimidazoles (1-BZ), levamisole (2-LV) and macrocyclic lactones (3-
59 ML). Widespread 1-BZ resistance has been reported throughout the UK (Cawthorne and
60 Whitehead, 1983; Sutherland et al., 1988; Grimshaw et al., 1994; Bartley et al., 2003;
61 Mitchell et al., 2010; Thomas et al., 2015), with a much lower number of 2-LV resistance
62 reports observed (Hong et al., 1994; Coles and Simkins, 1996; Mitchell et al., 2010) and
63 increasing reports of 3-ML resistance associated with multiple drug resistance to two or more
64 anthelmintic drug classes (Bartley et al., 2004; Sargison et al., 2005; Sargison et al., 2007;
65 Thomas et al., 2015). It is therefore increasingly apparent that taking steps toward
66 maintaining sustainable productivity in the growing face of anthelmintic resistance (AR) is
67 required by farmers.

68 In response to growing concerns of AR development in the UK sheep industry, the
69 Sustainable Control of Parasites in Sheep (SCOPS) initiative was set up in 2003. SCOPS is
70 an industry led group that represents the interests of the UK sheep industry with a remit to

71 develop and promote practical recommendations for producers and advisors regarding ‘best
72 practice’ approaches to parasite control (Abbott et al., 2012). Currently these
73 recommendations are summarised into eight guidelines each of which outline a variety of
74 measures to preserve the effectiveness of current and future anthelmintics. These eight
75 guidelines broadly cover the following aspects of best practice roundworm control including:
76 1) Working out a control strategy with a veterinary advisor 2) implementing an effective
77 quarantine strategy 3) testing for anthelmintic resistance, 4) administering anthelmintics
78 effectively 5) using anthelmintics only when necessary 6) selecting the appropriate
79 anthelmintics 7) preserving a susceptible worm population and 8) introducing alternative,
80 non-chemotherapeutic roundworm control strategies (Abbott et al., 2012). There are
81 numerous channels for the dissemination of the SCOPS recommendations such as through
82 animal health advisors (e.g. veterinarians, suitably qualified persons and researchers),
83 online/printed publications as well as face-to-face promotion at agricultural events. In other
84 sheep producing countries such as Australia, the current equivalent repository for information
85 and recommended practices regarding roundworm control *WormBoss* (Anonymous, 2016)
86 has achieved a high level of awareness amongst farmers. This is in part due to the effective
87 use of the internet platform including the use of an electronic support system. However steps
88 to measure and enhance the transition from awareness to adoption are an uncertainty
89 recognised by both extension schemes (Woodgate and Love, 2012; Anonymous, 2013)).

90 Various questionnaire surveys have been undertaken and published on the parasite
91 management practices of sheep farmers from around the world, as well as within the UK
92 (Coles, 1997; Bartley et al., 2004; Suter et al., 2005; Hughes et al., 2007; Lawrence et al.,
93 2007; Sargison et al., 2007; Morgan et al., 2012; McMahon et al., 2013). Such studies have
94 highlighted the variable adoption of sustainable roundworm control practices, and
95 emphasised the need to improve promotion and perception of these practices if sustainable

96 parasite control is to be generally accepted. In recent years the rapidly growing application of
97 socio-psychological research methods in behavioural science has highlighted their influence
98 on animal health decision making. These studies have investigated behaviours relating to a
99 wide range of disease management practices related to many livestock species as described
100 by Wauters & Rojo-Gimeno (2014). However, a limited amount of work has investigated
101 how socio-psychological factors may influence farmer's parasite control behaviours (e.g. Relf
102 et al., 2012; Vande Velde et al., 2015). Moreover few studies have employed the use of
103 quantitative modelling techniques to assess the extent at which such factors influence
104 farmers' parasite control behaviours. The measure of human behaviour in these studies has
105 either been indicated via behavioural intentions (e.g. Toma et al., 2015; Vande Velde et al.,
106 2015) or by respondents' self-reported behaviours (Toma et al., 2013). The use of
107 behavioural intention i.e. a readiness to perform a given behaviour has been proposed to be a
108 direct proxy for actual behaviour based on the widely applied theory of planned behaviour
109 model (Ajzen, 1991). Self-reported behaviour on the other hand requires respondents to
110 personally state their actions regarding a specific circumstance. More recent applications of
111 decision-making models have moved from primarily economic driven factors to also
112 incorporate non-economic influences such as farm characteristics, farmer demographics and
113 psychological factors. This helps to represent the range of both financial and non-financial
114 factors involved and their potential influences in the decision making process (Edwards-
115 Jones, 2006).

116

117 This study aims to use a quantitative statistical modelling approach to investigate the
118 influence of socio-psychological factors on the overall adoption of SCOPS practices and
119 practices recognised to be selective for the development of AR (designated AR selective
120 practices hereafter). By employing such methods this will help to evaluate potential

121 mitigation strategies to assist the adoption of best practice parasite management approaches.

122

123 **Material and methods**

124

125 Model framework

126 Attitudinal questionnaire items were initially devised based on a range of different source

127 material. Questions came from a combination of common themes highlighted from farmer

128 focus group meetings (unpublished data), as well as the research groups own parasite

129 management experience and comparable questionnaire literature related to disease

130 management (Bartley et al., 2003; Palmer, 2009; Toma et al., 2013; Alarcon et al., 2014;

131 Vande Velde et al., 2015). The emphasis for developing questions was to consider areas of

132 greatest importance to sheep farmers regarding parasite control, such as treatment timings,

133 benefits of anthelmintic treatments, dosing practice etc. The result of this was a

134 comprehensive list of items which were categorised into components based on the SCOPS

135 guidelines. Questions that were not specific to SCOPS practices were grouped under ‘general

136 attitudes’ to roundworm control and anthelmintic resistance. Additional items were derived

137 from behavioural models such as the Health belief model (HBM) which has been used to

138 explain and predict preventive health behaviours (Rosenstock et al., 1988). Such items

139 derived from this model include perceived level of risk, which comprises of susceptibility i.e.

140 likelihood of an event occurring, as well as severity i.e. the impact of the event occurring.

141 The combination of these risk items is referred to as ‘risk perception’ and was incorporated

142 into the general attitudes section of the questionnaire. Figure 1 illustrates the model

143 framework used in this paper to examine the influence of general roundworm control and AR

144 attitudes and farming demographic influences on the overall uptake of SCOPS and known
145 AR selective practices.

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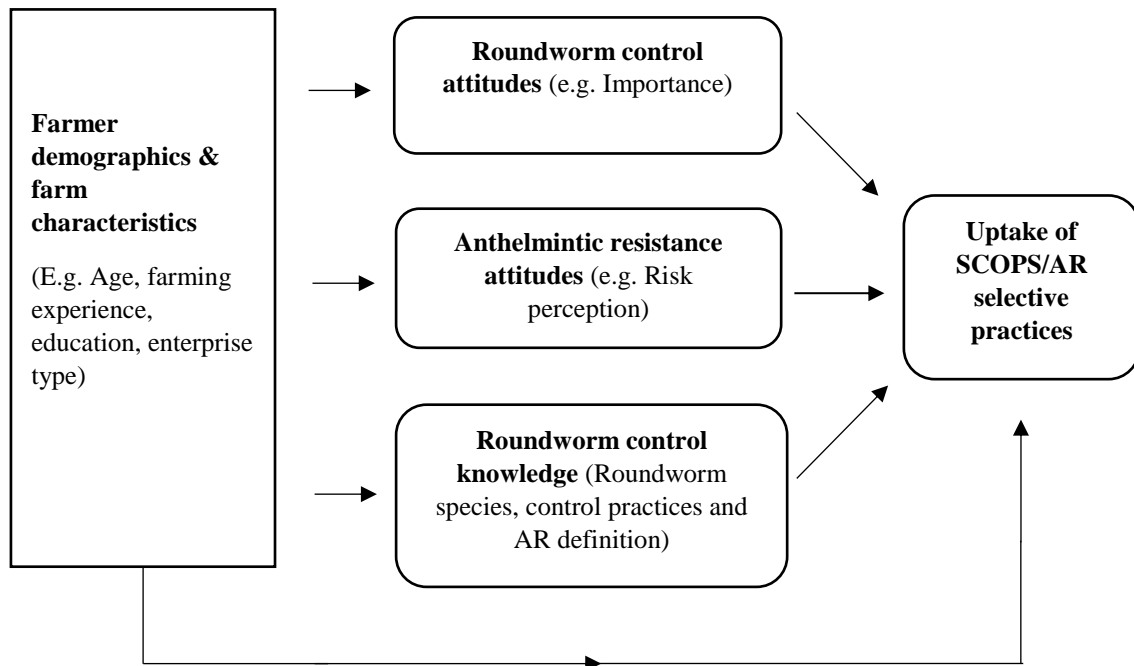
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Fig.1. Theoretical framework for general uptake of SCOPS recommended and AR selective roundworm control practices

163

164 Quantitative attitudinal survey design

165 The survey design was informed from the model framework (Figure 1) and built around four

166 main components which were arranged in the following order; 1) farmer demographics and

167 enterprise characteristics, 2) general roundworm control/AR attitude statements, 3) open-

168 ended roundworm control knowledge questions and 4) parasite control behaviours. The first

169 section included ten closed-ended questions relating to demographical information (age,

170 education and years earning a living as a farmer), as well as details of the farming system

171 (e.g. enterprise type, flock size, land topography, farming priorities). The second section
172 included 20 broader questions relating to attitudes towards general parasite control that were
173 not specific toward a particular control measure (e.g. the perceived importance of
174 roundworms, Attitudes to veterinary service and risk perception of AR). The third section
175 included three open-ended questions which were used to gauge the level of the respondent's
176 knowledge and understanding on the topic of roundworm control and AR. The final section
177 included 19 closed-ended questions of which 15 were directed to parasite control measures
178 implemented on farm. Four additional questions which included directly relating to the
179 behaviours of interest as well as preferred formats of knowledge transfer. All attitudinal
180 items included in section 2 were measured on a 5-point-Likert scale: Strongly Disagree (1),
181 Disagree (2), Unsure (3), Agree (4) and Strongly Agree (5). Sections 1 and 4 were recorded
182 by interviewers based on a pre-determined coding frame.

183 Survey implementation

184 Farmer contact details were obtained from the Scottish Government (Rural and
185 Environment Science and Analytical Services Division; RESAS) by the use of a stratified
186 simple random sampling method applied to the agricultural census data. The selection criteria
187 used to target farms of interest included, premises with flocks with more than 50 breeding
188 ewes and other sheep (1-year-old and over) for breeding, and at least 25 ewes used for
189 breeding in the previous season. This was to avoid sampling from particular smallholdings
190 where the motives for rearing livestock are not financially driven. The sampling frame was
191 further stratified regionally by animal health divisional office (AHDO) in order to ensure a
192 proportional population sample from each region. Based on a target of 400 completed surveys
193 from across six geographic regions of Scotland, the number required per region was weighted
194 based on the overall number of holdings within the region. The 400 target was established
195 based on a calculated sample size using the number of Scottish sheep holdings (approx.

196 14,900; National statistics) with an error rate of 5% and confidence level of 95% (Israel,
197 1992). The following equation was used to calculate the sample size for the questionnaire
198 where n is the sample size, N is the population size, and e is the level of precision (Yamane,
199 1967)

$$n = \frac{N}{1 + N(e)^2}$$

200 Opt-out letters were sent out to farmers two weeks prior to the implementation of the survey.
201 The letters outlined the aim of the study, the estimated interview duration, the voluntary
202 nature of the survey and gave assurance that any publication of results would ensure
203 anonymity. If the recipient did not reply to the opt-out letter within the specified time it was
204 considered that they had implicitly agreed to participate in the telephone interview.

205 A pilot study with six farmers was conducted before undertaking the main survey. This
206 informed the modification of questionnaire items ensuring no ambiguity of questions by
207 respondents and suitability of items for the telephone survey format. Additionally, lengths of
208 interviews were monitored to ensure that interview times were not excessive, in order to
209 achieve appropriate timeliness.

210 The survey interviews were conducted by a telecommunications company (Feedback Market
211 Research Ltd.) and responses were documented by the interviewer and compiled on a
212 Microsoft Excel spreadsheet. All interviews were conducted under internal quality assurance
213 procedures using computer assisted telephone interviewing systems. Farmers were assured
214 that all information provided would remain completely anonymous in any subsequent reports
215 or publications and that they and their enterprises would not be individually identifiable. Any
216 farmers wishing to opt out after the data was collected were able to do so.

217 **Data formatting/transformation**

218 The raw data was firstly coded into a database using Statistical Package for the Social
219 Sciences (SPSS, IBM SPSS Statistics version 22.0). The data was then assessed for normality
220 using the Kolmogorov-Smirnov statistical test. All variables included in the analysis were
221 recorded as per the original coding frame detailed in Table 2, with the exception of
222 ‘Education’, ‘Ewe numbers’ and ‘Roundworm control knowledge’. Categories other than
223 ‘agricultural college’ within ‘Education’ were considered to have little influence on
224 agricultural practice and were therefore combined. The continuous variable ‘Ewe numbers’
225 was categorised based on an evaluation of the data structure. The three open-ended
226 knowledge question responses were individually assessed and classified into a dichotomous
227 variable (i.e. correct or incorrect) based on the authors’ judgement. Two of the three
228 questions required the respondent to list specific examples of parasite species or roundworm
229 control practices. The third question required a description of their understanding of the term
230 wormer resistance, a correct response required a description of the basic principle i.e. a
231 reduction in the effectiveness of a drug treatment or an inherent ability of parasites to survive
232 drug treatment. A score was devised based on the number of correct responses to the three
233 questions.

234 The endogenous i.e. dependent variables (‘SCOPS practice uptake’ & ‘AR selective practice
235 uptake’) were formulated into ordinal scores by summing the total number of practices that
236 were identified as either ‘best practice’ or selective for AR development based on the SCOPS
237 manual (Abbot et al., 2012). The designation of AR selective practices was based on the
238 selection of behaviours which were converse to best practice approaches, also which were
239 impartial towards particular farming systems. The total number of practices identified as best
240 practice was ten, and the total number of AR selective practices identified was seven. Table 1
241 presents the descriptive statistics of the practices used to formulate both outcome variables

242 (i.e. SCOPS and AR selective practices) and figure 2 presents the frequency distributions of
 243 the outcome variables.

244 Table 1.

245 Respondents roundworm control behaviours associated with ‘SCOPS uptake’ and ‘AR selective’
 246 formulated scores ($n = 400$).

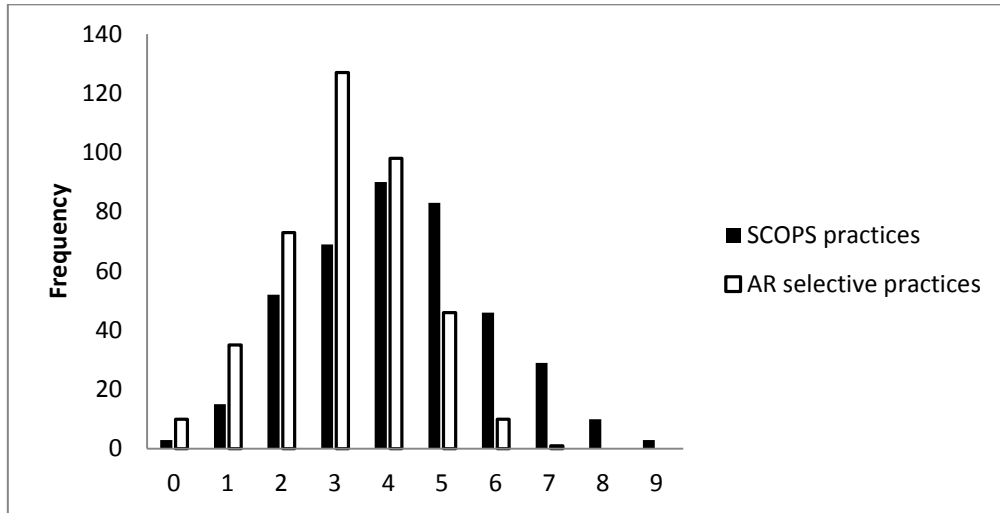
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Roundworm control practices	SCOPS recommended			AR selective		
	Levels	$n =$	%	Levels	$n =$	%
In the last 12 months how often have you sought advice specifically regarding roundworm control?	At least once	255	64	-	-	-
In the last 12 months how many times have you treated your ewes and lambs for roundworms?	Ewes (< average*)	90	23	Ewes (> average*)	172	43
	Lambs (< average†)	66	17	Lambs (> average†)	195	49
Do you monitor worm egg counts?	Yes	136	34	No	264	66
Do you drench incoming sheep brought onto the farm? ‡	Yes	303	94	No	20	6
Do you withhold sheep from pasture? ‡	Yes	221	68	No	102	32
Have you ever tested for drug resistance?	Yes	51	13	No	349	87
Do you move your animals immediately to clean pasture after treatment?	No	158	40	Yes	244	61
Do you use selective breeding for roundworm control in your flock?	Yes	49	12	-	-	-
Do you graze sheep and cattle together, graze separately or rotate grazing between the two?	Yes – Rotational	84	21	-	-	-
	Yes – Co-graze	134	36	-	-	-

248 *Ewe treatment average (2) † lamb treatment average (2) ‡ results exclude closed flock farms ($n = 77$)

249

250



251

252 Fig. 2 - Total number of SCOPS (filled bars) and AR selective (open bars) practices
253 employed by respondents ($n = 400$)

254

255 **Statistical analysis**

256 Factor analysis

257 Initial exploratory factor analysis was performed on ordinal (Likert Scale) items related to the
258 general uptake of SCOPS and AR selective practices, in order to identify and evaluate inter-
259 relationships between variables. Based on their covariation, the total number of observed
260 variables was condensed into a smaller set of unobserved (latent) factors. In the development
261 of the proposed models, items within section 2, i.e. general attitudes to roundworm control
262 section were assessed. The procedures for the assessment of factor loadings (correlation
263 coefficients) and reliability analysis (Cronbach alpha) were conducted as described by Hair et
264 al. (2006). Accordingly, based on the study sample size ($n = 400$), in order to achieve

265 statistical significance for each value with a statistical power of 80 per cent, a minimum
266 threshold of ± 0.30 factor loading was used. Factor loadings below ± 0.30 , or loadings that
267 demonstrated significant loadings across more than one factor i.e. cross loading, were not
268 included within the resultant factor. The internal reliability measure (Cronbach alpha) was set
269 at an approximate minimum threshold of 0.60 with a value > 0.70 indicating a good reliability
270 measure. Factors which demonstrated acceptable factor loadings and Cronbach alpha
271 measures were retained for further analysis. The method of extraction applied was Principal
272 Component Analysis. An orthogonal factor rotation method 'Varimax' was used to interpret
273 the extracted factors.

274

275 Structural equation modelling

276 In order to examine the inter-relationships between the observed and unobserved (latent)
277 variables in the proposed theoretical model (as represented in Figure 1), the analysis was
278 performed using the multivariate analysis technique known as Structural Equation Modelling
279 (SEM). This technique comprises of two parts, the first is the measurement model which
280 represents the relationships between the specified indicators and their latent constructs. The
281 second part is the structural model which then examines the relationships between the model
282 constructs. The relationship between variables as measured by the regression coefficient
283 represents the change in the dependent variable for one unit change in the independent
284 variable. The regression coefficients are standardised (β values) in order to allow direct
285 comparisons of the relative effects of each variable on the dependent variable. The individual
286 effects are estimated independent of the effects of the other variables to allow assessment of
287 individual relationships within the model (i.e. ceteris paribus). All factors were included in
288 both models with the exception of 'Vet service pros' and 'Vet service cons' which were

289 selected for ‘SCOPS practice uptake’ and ‘AR selective practice uptake’ respectively The
290 statistical package Lisrel 8.80 (Jöreskog and Sörbom, 2007) was chosen for the purposes of
291 the SEM analysis. Due to the non-normality of the explanatory variable data, a Diagonally
292 Weighted Least Squares (DWLS) method was used to estimate the model parameters. The
293 resulting model output was evaluated for goodness of fit by using the following model fit
294 indices as detailed by Hair et al. (2006); Root Mean Square Error of Approximation
295 (RMSEA), Standardised Root Mean Residual (SRMR), Comparative Fit Index (CFI),
296 Incremental Fit Index (IFI), Goodness of fit (GFI), Adjusted Goodness of Fit Index (AGFI)
297 and Normed Fit Index (NFI).

298

299 **Results**

300

301 **Participant descriptive statistics**

302 The total number of opt-out letters received from the original 1,930 farmers contacted was
303 427 (22%), leaving 1,503 farmers eligible to be contacted. The target of 400 completed
304 interviews was achieved with the following numbers of interviews resulting from each
305 region: 65 in the South East, 76 in the South West 74 in Central region, 92 in the North West,
306 46 in the North East, and 47 in the Islands.

307 In terms of respondents demographic responses, the majority of farmers (69%) in the survey
308 sample were aged in the 51-65 or >65 year brackets with only 3% of the respondents
309 representing the youngest age bracket (18-35). The number of years earning a living as a
310 farmer was normally distributed with less of a skew towards more experienced farmers. The
311 level of education showed that most respondents (55%) had had some degree of further
312 education, with approximately 35% studying at an agricultural college.

313 In regards to the farming enterprises, almost two thirds of respondents' farms were situated
 314 on either upland or hill grazing land, with over half of the sample population comprising of
 315 mixed livestock farmers and a quarter sheep-only farmers. The proportional flock sizes as
 316 indicated by numbers of breeding ewes are more orientated towards small to medium sized
 317 flocks (i.e. <500 ewes), with a quarter of farms with larger flocks (>500 ewes).

318

319 Table 2

320 Description of latent constructs with corresponding indicators and Cronbach alpha reliability measures (α)

Latent variable	Statement	α	Value and labels	Variable type
Experience	What is your age?	0.764	1 = 18-35; 2 = 36-50; 3 = 51-65; 4 = over 65	Categorical
	How many years have you been earning a living as a farmer?		1 = 10 years or less; 2 = 11-20; 3 = 21-30; 4 = 31-40; 5 = 41-50; 6 = over 51	Categorical
Education	Did you attend a place of further education?	NA	0 = no or yes, education other than agriculture college 1 = yes, Agricultural college	Binary
Ewe numbers	Number of breeding ewes?	NA	1 = 0-100; 2 = 101-200; 3 = 201-500; 4 = 501-1000; 5 = 1001 or more	Categorical
Enterprise type	Is your farm: sheep only, mixed livestock or livestock and arable?	NA	0 = sheep only; 1 = mixed livestock; 2 = livestock and arable	Categorical
Topography	Is your farm designated as lowland, upland or hill?	NA	0 = lowland; 1 = upland; 2 = hill	Ordinal
Worm control knowledge	Knowledge score	NA	0 = none correct; 1 = one correct; 2 = two correct; 3	Ordinal

			= three correct	
Occurrence of worm problems	How would you classify the occurrence of roundworm problems in your flock?	NA	0 = low; 1 = moderate; 2 = high	Ordinal
AR confirmation	Do you have confirmed drug resistance?	NA	1= no 2= yes	Binary
Worm control importance	1. - Roundworm control is important on my farm	0.877	5-point Likert scale ^a	Ordinal
	2. - My roundworm control strategy improves the productiveness of my animals		5-point Likert scale ^a	Ordinal
	3. - Roundworm control is important for the profitability of my farm		5-point Likert scale ^a	Ordinal
	4. - Roundworm control is important for the health & welfare of my animals		5-point Likert scale ^a	Ordinal
AR risk	1. - Wormer resistance is a problem in my region	0.593	5-point Likert scale ^a	Ordinal
	2. - Wormer resistance is a threat to my farming business		5-point Likert scale ^a	Ordinal
Vet service pros	1. - Working with my vet could improve my roundworm control strategy	0.877	5-point Likert scale ^a	Ordinal
	2. - Working out a roundworm control strategy with my vet is cost effective		5-point Likert scale ^a	Ordinal
	3. - Working out a roundworm control strategy with my vet ensures I get reliable advice		5-point Likert scale ^a	Ordinal
Vet service cons	1. - Roundworm control advice provided by vets is too complex	0.81	5-point Likert scale ^a	Ordinal
	2. - Roundworm control advice provided by vets is difficult to implement		5-point Likert scale ^a	Ordinal
SCOPS practice uptake	Number of SCOPS practices implemented	NA	0 = none; 1 = one; 2 = two;, 3 = three; 4 = four; 5 =	Ordinal

five; 6 = six; 7 = seven; 8 =
eight; 9 = nine; 10 = ten

AR selective practice uptake	Number of AR selective practice implemented	NA	0 = none; 1 = one; 2 = two;, 3 = three; 4 = four; 5 = five; 6 = six; 7 = seven;	Ordinal
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321 ^a 5-point Likert scale: 1 = Strongly disagree; 2 = Disagree; 3 = Unsure; 4 = Agree; 5 = Strongly agree

322

323 Results of factor analysis

324 Both of the models proposed consist of seven single-indicator latent variables and four
325 multiple-indicator latent variables as detailed in Table 2. The exploratory factor analysis
326 established acceptable factor loadings i.e. > 0.70 for all multiple-indicator latent variables
327 (Presented in Appendix A). Additionally, the Cronbach alpha reliability analysis shown in
328 Table 2, demonstrated suitable measures ($\alpha > 0.60$) between all sets of indicators with the
329 exception of 'AR risk'.

330 Results of structural equation models

331 Both models reflected a goodness of fit with the observed data as indicated by the following
332 model fit indices as according to Hair et al (2006). Significance was established for all
333 relationships at a 0.05 level, with significant standardised coefficients (total effects) of both
334 models detailed in tables 3 and 4. An illustrated version of the direct influences on SCOPS
335 practice uptake model is presented in Figure 3; however, this was not feasible in the 'AR
336 selective practice' model due to the large number of estimates identified. The SCOPS model
337 fit values were below the maximum threshold of 0.10 for RMSEA at 0.025, and at the 0.08
338 threshold for SRMR (0.08), for the subsequent fit indices values above 0.90 give an
339 indication of acceptable fit; CFI (0.99), IFI (0.99), GFI (0.98), AGFI (0.97) and NFI (0.96).
340 The SCOPS model explained 54% of the variance in the adoption score of sustainable

341 parasite control practices. The factors which had the greatest direct positive effects on
342 SCOPS uptake were 'AR confirmation' ($\beta = 0.55$) followed by 'Enterprise type' ($\beta = 0.30$),
343 'AR risk' ($\beta = 0.21$) and 'Vet service pro' ($\beta = 0.20$). The greatest indirect positive influence
344 on SCOPS uptake was 'Worm control knowledge' ($\beta = 0.34$) mediated by 'AR confirmation'
345 ($\beta = 0.61$). Exogenous factors which were shown to have a positive influence on mediating
346 factors included 'Ewe numbers' with a strong effect on 'AR confirmation' ($\beta = 0.43$) and a
347 moderate effect on 'Occurrence of worm problems' ($\beta = 0.20$). In addition to 'Education'
348 with a positive effect on 'AR risk' ($\beta = 0.31$) and 'Worm control importance' with a positive
349 influence on 'Vet service pro' ($\beta = 0.36$). Factors which demonstrated a negative influence on
350 SCOPS uptake through mediating factors included 'Experience' on 'AR risk' ($\beta = -0.16$) and
351 'Worm control knowledge' ($\beta = -0.31$) as well as 'Topography' with moderate influences on
352 'Worm control knowledge' ($\beta = -0.24$).

353 The AR selective practice model fit indices were as follows; RMSEA (0.050), SRMR
354 (0.083), CFI (0.93), IFI (0.94), GFI (0.97), AGFI (0.96) and NFI (0.90). The AR model
355 explained 47% of the variance in the adoption of recognised AR selective roundworm control
356 practices. Factors shown to have the greatest positive influence on the use of AR selective
357 practices included 'Vet service con' with a direct effect on the behavioural outcome ($\beta =$
358 0.14), in addition to 'Experience' ($\beta = 0.12$) and 'Topography' ($\beta = 0.08$) which both had
359 indirect influences on AR selective practices. The greatest direct negative influence on AR
360 selective practices was associated with 'AR confirmation' ($\beta = -0.67$). Indirect negative
361 influences on AR selective practices included 'Worm control knowledge' ($\beta = -0.34$), 'Ewe
362 numbers' ($\beta = -0.16$), 'AR risk' ($\beta = -0.15$), 'Education' ($\beta = -0.11$), 'Enterprise type' ($\beta = -$
363 0.06) and 'Worm control importance' ($\beta = -0.03$).

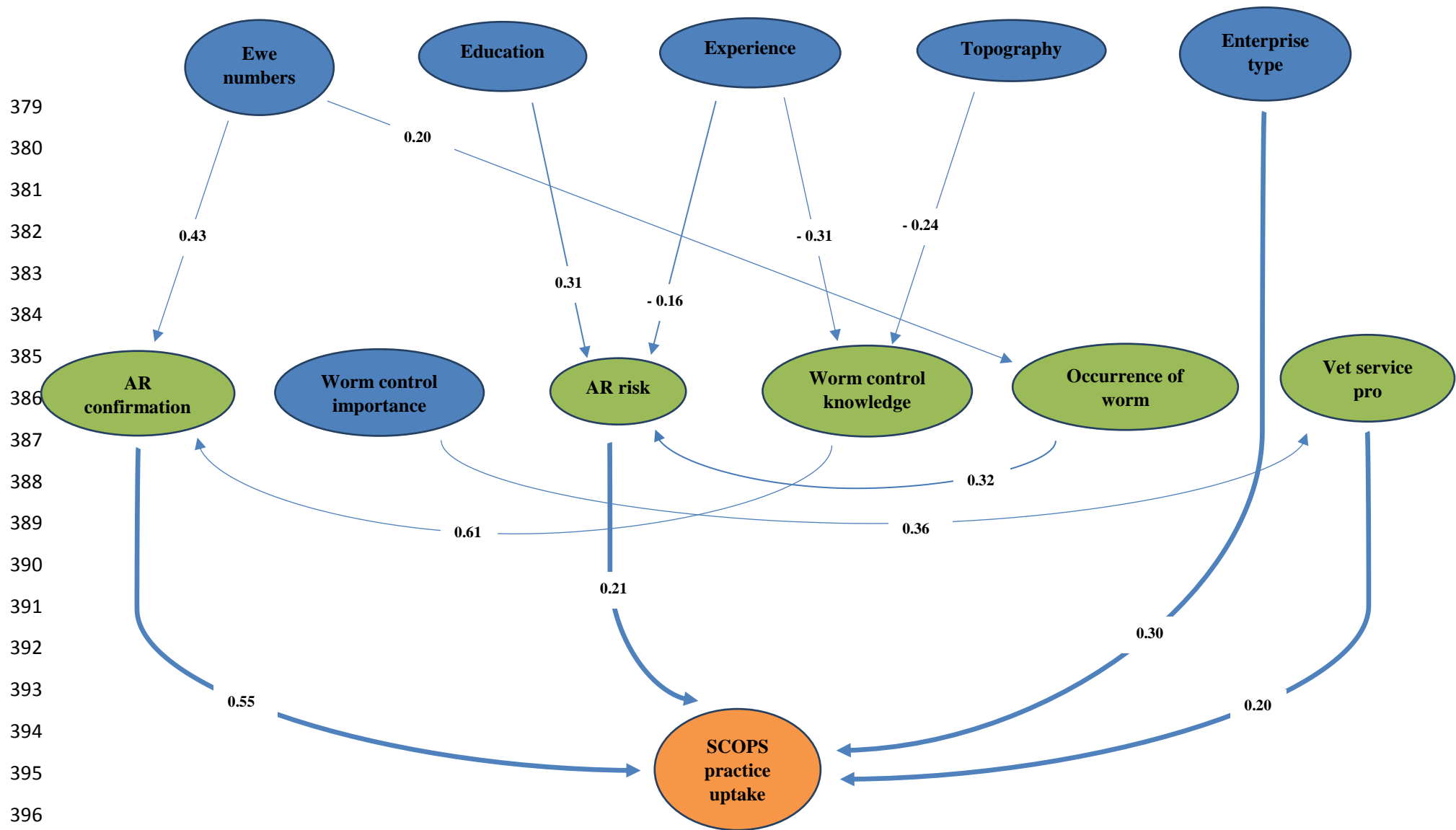
364 The factor 'AR confirmation' was shown to be directly influenced positively by 'Worm
365 control knowledge' ($\beta = 0.51$), 'Ewe numbers' ($\beta = 0.33$) and 'AR risk' ($\beta = 0.22$), Indirect

366 mediated influences included 'Education' ($\beta = 0.16$), 'Enterprise type' ($\beta = 0.09$) and 'Worm
367 control importance' ($\beta = 0.04$). 'AR confirmation' was most negatively influenced by
368 'Experience' ($\beta = -0.18$) and 'Topography' ($\beta = -0.13$). The factor 'AR risk' attitudes were
369 shown to be most positively influenced directly by 'Occurrence of worm problems' ($\beta =$
370 0.34), 'Education' ($\beta = 0.26$) and negative influenced by 'Experience' ($\beta = -0.20$) and
371 'Typography' ($\beta = -0.15$). The factor 'Worm control knowledge' was influenced directly by
372 five factors including most prominently 'Experience', ($\beta = -0.27$) followed by 'Education' ($\beta =$
373 0.21), 'Topography' ($\beta = -0.18$), 'Enterprise type' ($\beta = 0.17$) and 'Ewe numbers' ($\beta = 0.13$).
374 The factor 'Occurrence of worm problems' was influenced positively by 'Ewe numbers' ($\beta =$
375 0.24).

376

377

378



397 Fig.3. SCOPS uptake structural model (standardised solution). Bold arrows represent the direct influences of latent variables on the behavioural latent 'SCOPS practice uptake', with non- bold arrows representing the
 398 direct effect influences on other latent variables. The corresponding numbers are the standardised coefficients of the variables in the structural model. Blue variables denote variables that are exogenous i.e. independent
 399 from other variables in the model, with green variables taking either exogenous or endogenous roles i.e. influenced by other variables. The orange variable represents the endogenous behavioural latent variable.

400 Table 3.

401 Standardised total effects on SCOPS model latent variables (Standard error values)

Total (direct and indirect) effects on effector variables							
Determinants	'SCOPS practice uptake'	'AR Confirmation'	'Worm control Importance'	'AR risk'	'Worm control knowledge'	'Occurrence of worm problems'	'Vet service pro'
'Ewe numbers'	0.25 (0.04)	0.43 (0.08)	-	0.06 (0.03)	-	0.20 (0.03)	-
'Education'	0.06 (0.03)	-	-	0.31 (0.14)	-	-	-
'Experience'	-0.14 (0.05)	-0.19 (0.06)	-	-0.16 (0.11)	-0.31 (0.05)	-	-
'Topography'	-0.08 (0.03)	-0.14 (0.05)	-	-	-0.24 (0.05)	-	-
'Enterprise type'	0.30 (0.12)	-	-	-	-	-	-
'AR Confirmation'	0.55 (0.09)	NA	-	-	-	-	-
'Worm control Importance'	0.07 (0.03)	-	NA	-	-	-	0.36 (0.06)
'AR risk'	0.21 (0.06)	-	-	NA	-	-	-
'Worm control knowledge'	0.34 (0.11)	0.61 (0.14)	-	-	NA	-	-
'Occurrence of worm problems'	0.07 (0.05)	-	-	0.32 (0.18)	-	NA	-
'Vet service pro'	0.20 (0.07)	-	-	-	-	-	NA
R-square	0.54	0.56	-	0.27	0.16	0.04	0.13

402

403

404

405 Table 4.

406 Standardised total effects on AR model latent variables (Standard error values)

Total (direct and indirect) effects on effector variables							
Determinants	'AR selective practice uptake'	'AR Confirmation'	'Worm control Importance'	'AR risk'	'Worm control knowledge'	'Occurrence of worm problems'	'Vet service cons'
'Ewe numbers'	-0.16 (0.05)	0.33 (0.07)	-	0.08 (0.02)	0.13 (0.03)	0.24 (0.04)	-
'Education'	-0.11 (0.04)	0.16 (0.05)	-	0.26 (0.07)	0.21 (0.06)	-	-
'Experience'	0.12 (0.04)	-0.18 (0.05)	-	-0.20 (0.05)	-0.27 (0.04)	-	-
'Topography'	0.08 (0.04)	-0.13 (0.04)	-	-0.15 (0.05)	-0.18 (0.09)	-	-
'Enterprise type'	-0.06 (0.06)	0.09 (0.07)	-	-	0.17 (0.04)	-	-
'AR Confirmation'	-0.67 (0.10)	NA	-	-	-	-	-
'Worm control Importance'	-0.03 (0.02)	0.04 (0.02)	NA	0.18 (0.05)	-	-	--
'AR risk'	-0.15 (0.08)	0.22 (0.09)	-	NA	-	-	-
'Worm control knowledge'	-0.34 (0.13)	0.51 (0.13)	-	-	NA	-	-
'Occurrence of worm problems'	0.18 (0.15)	0.08 (0.05)	-	0.34 (0.10)	-	NA	-
'Vet service cons'	0.14 (0.07)		-	-	-	-	NA
R-square	0.47	0.44	-	0.28	0.19	0.06	-

407

408 Discussion

409 The results demonstrate that of the nine significant factors positively influencing the uptake
410 of SCOPS recommended practices, the confirmation of AR on a particular holding is shown
411 to have the greatest influence towards the uptake of sustainable parasite control practices.

412 This would suggest that such an event is likely to have the greatest impact on farmer's
413 decision making, which may demonstrate a decisive mechanism for prompting farmers

414 directly affected by AR to assess their treatment efficacies. Farmers may be motivated to
415 modify their parasite control strategies based on the knowledge of which nematode species
416 are resistant to a particular class of anthelmintic, which will help to ensure the preserved
417 effectiveness of the other remaining anthelmintics. The challenge therefore is to encourage
418 farmers to test their treatment efficacies in the absence of indication or a critical event, which
419 has also been acknowledged as a barrier for dairy farmers to reassess their routines regarding
420 mastitis control (Dillon, 2015).

421 The level of farmer's roundworm control knowledge is likely to reflect their awareness and
422 understanding of the topic, which is fundamental to the decision making process. The impact
423 of knowledge on SCOPS uptake emphasises the importance of informing farmers about areas
424 such as roundworm identification, non-chemical control measures and AR as a vital target for
425 influencing farmer's roundworm practices. Furthermore, knowledge was also identified as a
426 strong determinant for establishing AR status which as previously stated may further
427 influence the adoption of SCOPS practices. The negative effect of knowledge on AR practice
428 uptake also demonstrates the influence of SCOPS awareness towards the adoption of
429 sustainable roundworm practices. In another study using SEM, Toma et al (2015) also
430 identified disease control knowledge to directly and indirectly influence farmer's behavioural
431 intentions. The use of farmers' workshops has been one such strategy employed to engage
432 farmers through providing information as well as setting up subsidised faecal egg count
433 monitoring programmes with local veterinary practices during the peak grazing season
434 (Anonymous, 2016). The dual benefits of this type of approach may come from ways of
435 improving motivation as well as providing an added financial incentive. Steers and Porter
436 (1975) suggested motivation may be a result of firstly stimulating an initial interest on a topic
437 (i.e. energising), directing participants to learn and master the topic (director) and then
438 reinforcing the knowledge and skills acquired (i.e. maintenance). The maintenance of

439 engagement has also been stated as an important aim to achieving behavioural change in the
440 medium to long-term future (Rushmer et al., 2014). The use of economic incentives such as
441 cost-sharing as described in this instance may spur participation from those farmers with a
442 pre-existing interest on the subject, however for those without interest this may have little or
443 no long term effect on the adoption of such sustainable agricultural practices (Rodriguez et
444 al., 2009). The method used to formulate the knowledge score meant that the level of detail in
445 participant's responses was not factored into the analyses. This will therefore have a limiting
446 effect on the depth of understanding attributed to participant responses. Further work may
447 benefit from assessing the influence of superficial vs. in-depth parasite knowledge on the
448 effectiveness of implementing behaviours.

449 With regards to attitudinal factors, farmers' AR risk perception presented a moderate
450 influence on the uptake of SCOPS practices and a comparable negative influence on AR
451 selective practices. This may suggest that Scottish farmer's perceptions of AR risk in terms of
452 susceptibility and impact may not be as influential as other factors, possibly due to the
453 progressive 'invisible' nature of AR development in comparison with other disease threats
454 (Woodgate and Love, 2012). In fact, the proportion of respondents' disagreeing that AR is a
455 problem in their region or that AR is a threat to their farming business was 42% and 42%
456 respectively. Positive attitudes towards veterinarians' roundworm control services was also
457 shown to influence the uptake of SCOPS practices as would be anticipated due to their
458 prominent role in educating and encouraging sustainable farming practices. The importance
459 of veterinarians as an influential source of roundworm control information was stated by 65%
460 of respondents, and is also widely acknowledged in the literature (Brennan and Christley,
461 2013; Alarcon et al., 2014). These findings, in support of others e.g. Kaler and Green (2013)
462 reinforce the need to improve interactions between sheep farmers and veterinarians to

463 encourage more farmers to introduce improvements to their current roundworm control
464 strategies, as part of their overall flock health plans.

465 Farming characteristic factors such as ewe numbers and enterprise type were also shown to
466 positively influence SCOPS uptake. The effect of flock size may vary the relative importance
467 and impacts attributed to roundworm control. For instance, larger flocks would typically be
468 more associated with greater stocking densities resulting in a higher parasite infection
469 pressure, due to increased pasture contamination. Hence there is a greater requirement for
470 such farms to employ various measures in order to mitigate production losses, as well as
471 address mounting concerns over reliance on chemical control methods. Willock et al., (1999)
472 also found farm size to be a significant influence to farmer's decision making. Enterprise type
473 was shown to have a considerable direct influence on the uptake of SCOPS practices, which
474 would suggest that farms with a greater diversity of farm enterprises are more likely to adopt
475 'best practice' advise. This would support the findings of other studies where more farm
476 enterprises was shown to influence the adoption of best management practices in cattle
477 production (Kim, 2005). The topography of respondent's farms was also shown to have a
478 relatively small direct influence on adoption of SCOPS behaviours with upland/hill farms less
479 likely to employ such practices. This might be due to the contrasting management systems
480 between lowland and hill farms with greater labour requirements to gather and manage an
481 extensively run flock (Morgan-Davies et al., 2006).

482 Factors that were shown to have a low direct effect on SCOPS uptake included: the
483 occurrence of roundworm control problems, education, topography and perceived
484 roundworm control importance. These factors however demonstrated a greater direct effect
485 through mediating factors such as AR risk, AR confirmation, vet services pro and knowledge.
486 An agricultural college education was shown to positively influence AR risk perception
487 whereas experience was shown to negatively influence numerous factors including

488 knowledge, AR risk and establishing AR status. The negative influence of other internal
489 factors such as experience suggest that more experienced farmers are less likely to employ
490 sustainable parasite control measures, perhaps due to a greater reliance on their own sense of
491 judgement (Garforth et al., 2013; Kaler and Green, 2013). This concept of self-identity in
492 relation to the importance of farmers own abilities to identify problems poses a likely barrier
493 towards more experienced farmers seeking external guidance regarding roundworm control
494 (Thompson, 2008). This is particularly relevant considering the high proportion of surveyed
495 respondents aged above 51 years of age in contrast with the younger age brackets, which are
496 comparable with most recent agricultural census reports (National Statistics, 2015)

497 The identification of factors with the greatest influences on best practice uptake can be used
498 to direct future extension programmes towards areas where greatest impact may be expected
499 to occur, such as developing communication strategies highlighting the benefits of diagnostic
500 testing. The utilisation of local veterinary services as a highly trusted resource is likely to
501 appeal most to farmers as this will also facilitate the tailoring of advice to suit the
502 management strategies in their particular enterprises. The main difficulty of this however is
503 the availability of sheep specialist veterinarians with the interest and expertise required to
504 engage farmers on a wider level (Kaler and Green, 2013). Another approach could be to
505 further support the training of animal health advisors as well as those teaching at agricultural
506 colleges, which as demonstrated could help to encourage the next generation of young
507 farmers to adopt best practice parasite management approaches. Finally, lessons could also be
508 taken from other disciplines associated with influencing farmer perceptions and behaviours
509 such as in the agricultural business and marketing sectors. By developing a suite of strategies
510 to address farmers' perceptions and awareness of best practice advice, this will more likely
511 have a greater general impact than using one such approach in isolation.

512

513 **Conclusions**

514 The use of structural equation modelling has identified a number of significant factors
515 influencing farmer's parasite control behaviours. Both internal and external factors are shown
516 to influence the adoption of SCOPS and AR selective practices including most prominently
517 parasite control knowledge and the identification of AR. Such factors will inform and prompt
518 farmers to think more proactively regarding their roundworm control strategies in order to
519 preserve the effectiveness of remaining anthelmintic treatments. The influence of external
520 factors such as flock size, enterprise type and topography highlight the possible benefits of
521 tailoring future recommendations to suit the range of farming systems present in the sheep
522 farming industry and the challenges associated within these settings.

523

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529

530 **Conflict of interest**

531 None

532

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