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An analysis of cattle farmers' perceptions of drivers and barriers to on-farm control of *Escherichia coli* O157

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SUMMARY

Structural equation modelling and survey data were used to test determinants' influence on farmers' intentions towards *Escherichia coli* O157 on-farm control. Results suggest that farmers more likely to show willingness to spend money/time or vaccinate to control *Escherichia coli* O157 are those: who think farmers are most responsible for control; whose income depends more on opening farms to the public; with stronger disease control attitudes; affected by outbreaks; with better knowledge and more informed; with stronger perceptions of biosecurity measures' practicality; using a health plan; who think farmers are the main beneficiaries of control; and whose farms are dairy rather than beef. The findings might suggest that farmers may implement on-farm controls for *E. coli* O157 if they identify a clear hazard and if there is greater knowledge of the safety and efficacy of the proposed controls.

Key words: Attitudes and behaviour, *E. coli* O157 on-farm control, information and knowledge, structural equation modelling, UK cattle farmers.

INTRODUCTION

There is increasing evidence that the farm environment is an important hazard resulting in a considerable number of sporadic *Escherichia coli* O157 infections [1–6]. The presence of *E. coli* O157 in animal manure can lead to contamination of soil and grass, farm buildings, fences, machinery and water-courses, and the organism may survive for months in animal faeces and soil. In relation to measures for the control of *E. coli* O157 on-farm, EU food regulations recognize that 'The application of the Hazard Analysis and Critical Control Point (HACCP) principles to primary production is not yet generally feasible. However, guides to good practice should encourage the use of appropriate hygiene practices at farm level' [7, p. 5]. Despite significant effort in the past 10 years to understand the carriage of *E. coli* O157 by cattle both on and between farms, current knowledge is still incomplete thus limiting the understanding of what can be assumed as good practice for on-farm control. An additional potential constraint to on-farm control is the fact that no production losses are associated with cattle infection and therefore controls are necessary only to prevent human infection.

Applying *E. coli* O157 control measures on-farm is assumed to decrease the risk of transmission of *E. coli* O157 disease from livestock to humans and, implicitly,

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reduce the risks posed by *E. coli* O157 to human health. Understanding which determinants influence farmers' behavioural intentions and, potentially, behaviour towards livestock disease control has been the focus of a number of research studies over time and increasingly so during the past couple of decades.

The study analyses the impact of *a priori* determinants on adoption of *E. coli* O157 on farm control measures by cattle farmers in the UK. We used a dataset collected through a stratified telephone survey and analysed it using a structural equation model (SEM) based on behavioural economics theory. This is, to the best of our knowledge, the first paper using SEM applied to representative survey data to analyse farmers' attitudes and intentions to control *E. coli* O157 on farm.

METHODS

Research hypotheses

Based on a review of literature and expert opinion, we built and tested five research hypotheses:

Hypothesis 1: Farm characteristics (e.g. farm type; use of a livestock health plan; income from opening the farm to public) influence farmers' willingness to control E. coli *O157 on farm.*

Farm characteristics influence the type of disease control measures required and the level of investment (financial or labour) needed [8, 9]. As well as the farm's physical constraints, the financial situation of the enterprise will impact on what measures the enterprise can afford to implement [10, 11]. Some authors [12] found that pig and sheep farmers did not see health plans as a useful disease risk measure and mostly members of farm assurance schemes were more likely to have one. Other research [9] found that membership in cattle/sheep health schemes influenced biosecurity behaviour indirectly through other factors such as access to information and advice.

Hypothesis 2: Farmers' access to information and knowledge about E. coli *O157 influences their willingness to control* E. coli *O157 on farm.*

An important factor influencing farmer behaviour is the access to information on disease control measures and animal health issues. Some authors [12] found that improving farmers' access to information, targeting it through training events, the farming press, veterinarians, farmer groups, and tailoring it to different categories of livestock farmers could increase uptake of disease risk measures. Several studies analysed the importance of knowledge (awareness) of *E. coli* O157 of farmers, among other stakeholders, in influencing behaviours and dealing with *E. coli* O157 risk and prevention [13–15].

Hypothesis 3: Incidence of outbreaks on farm influences farmers' willingness to control E. coli *O157 on farm.*

In an outbreak situation the perceived and potential risks are elevated and the likelihood of farmers' implementing measures to control the disease increases significantly [9, 16–19]. Garforth *et al.* [12] found that farmers associated risk with the local disease status. If they were aware of neighbours' livestock having a transmittable disease, they were likely to take additional precautions. Additionally, their study [12] found that several farmers who stated they stopped vaccinating against some diseases when the risk was low said that they would consider vaccinating again if the disease risk increased in the area.

Hypothesis 4: Farmers' perceived practicality of E. coli *O157 on-farm control measures (e.g. biosecurity) influences their willingness to control* E. coli *O157 on farm.*

The literature has established that farmers are more likely to take up disease control measures if they find them practical/suitable to their farms. Braun *et al.* [20] found that demonstrations of successful implementation of biosecurity measures and their benefits increase the level of uptake. One study [21] used best-worst scaling to elicit experts' assessment of the relative practicality and effectiveness of measures to reduce human exposure to *E. coli* O157, while another study [12] found that farmers perceived the impracticality of some measures as constraints to the ability to implement them.

Hypothesis 5: Farmers' attitudes and perceptions regarding benefits of and responsibility towards E. coli *O157 on-farm control influence their willingness to control* E. coli *O157 on farm.*

Farmers' attitudes towards and perceptions of disease control measures have an important role in farm decision-making processes and, more specifically, in disease control behaviour [9, 10, 12, 13].

SEM

We used SEM with observed and latent variables to test the hypotheses and assess the strength of these relationships, i.e. how much these factors influence one another and primarily the behavioural willingness to control *E. coli* O157 on farm. As each variable will influence behavioural willingness both directly or indirectly (through their effect on other variables in the model, which in turn will directly influence behavioural willingness), the variance explained by the model is higher than when other techniques, such as regression analysis, are used [22].

The model consists of two parts, namely the measurement model (which specifies the relationships between the latent variables and their constituent indicators), and the structural model (which designates the causal relationships between the latent variables). The model is defined by the following system of three equations in matrix terms [22]:

the structural equation model: $\eta = B\eta + \Gamma\xi + \zeta$,
the measurement model for y: $y = \Lambda_y \eta + \varepsilon$,
the measurement model for x: $x = \Lambda_x \xi + \delta$,

where η is an m*1 random vector of endogenous latent variables; ξ is an n*1 random vector of exogenous latent variables; B is an m*m matrix of coefficients of the η variables in the structural model; Γ is an m*n matrix of coefficients of the ξ variables in the structural model; ζ is an m*1 vector of equation errors (random disturbances) in the structural model; y is a p*1 vector of endogenous variables; x is a q*1 vector of predictors or exogenous variables; Λ_y is a p*m matrix of coefficients of the regression of y on η; Λ_x is a q*n matrix of coefficients of the regression of x on ξ; ε is a p*1 vector of measurement errors in y; δ is a q*1 vector of measurement errors in x.

We performed model estimation with the diagonally weighted least squares (DWLS) method using the statistical package Lisrel 8·80 [22]. We combined Prelis (to analyse the raw data and compute the asymptotic covariance matrix) and Lisrel (to obtain estimates and test statistics, e.g. t test values, which estimate the statistical significance of causal relationships). SEM estimation is performed by minimizing the discrepancy between the covariance matrix of observed variables and the theoretical covariance matrix predicted by the model structure, which is a function of the unknown parameters. For the case of discrete indicators, Muthén [23] and others developed procedures based on the application of polychoric correlations (rather than the Pearson correlations used for continuous indicators) to estimate the covariance matrix of the latent continuous indicators from the discrete indicators. Consistent estimates of the parameters can then be obtained by minimizing the discrepancy between the estimated covariance matrix and the theoretical covariance matrix [24]. DWLS estimation method is consistent with the types of variables included in the model (ordinal and categorical) and the deviation from normality in some of these variables [25].

The model is validated using absolute, incremental and parsimonious goodness-of-fit (GoF) indicators [26]. The absolute fit indicators include: root mean square error of approximation and GoF index. Incremental fit indicators include: adjusted GoF index, non-normed fit index, normed fit index, relative fit index, comparative fit index and incremental fit index. Parsimonious fit indicators include normed χ^2.

An acceptable level of overall GoF does not guarantee that all constructs meet the requirements for the measurement and structural models. The validity of the SEM is assessed in a two-step procedure, the measurement model and the structural model. In the measurement model the reliability of single-indicator latent variables is tested using the 'theory-testing extremes' of reliability within the range of 0·7–1 [27] to determine if any structural coefficients become non-significant at these extremes.

Model selection is performed using a nested model approach, in which the number of constructs and indicators remains constant, but the number of estimated relationships changes.

The structure of the model was based on the survey questionnaire detailed in the following 'Questionnaire and survey' section.

Questionnaire and survey

The questionnaire was built based on a review of the literature, and expert opinion was used to develop it into its final version. The questionnaire was circulated in several rounds to experts from academia, the private sector and the policy environment, e.g. from the Scottish Agricultural College (currently SRUC), University of Glasgow, Bioniche Life Sciences, Food Standards Agency, Department for Environment, Food and Rural Affairs (Defra), who commented on the design of the questionnaire.

Table 1. *Description of latent variables and their corresponding indicators*

Latent variable	Indicators (statements)	Values and labels
farmtype	Type (type of farm – dairy or beef)	1 = dairy farm; 2 = beef farm
hplan	Health (use of a health plan written for the farm with assistance from the farm's veterinary surgeon to manage the health of livestock)	0 = no; 1 = incomplete; 2 = yes
income	Open (proportion of farm income dependent on opening to the public)	1 = <5%; 2 = 5–49%; 3 = 50–99%; 4 = 100%
Info	Source of general information for managing the farm: info1 (other farmers); info2 (agricultural consultants); info3 (sales people); info4 (veterinary surgeons); info5 (government); info6 (industry organizations)	0 = never; 1 = infrequently; 2 = frequently
know	know1 (livestock are an important source from which *E. coli* O157 spreads); know2 (*E. coli* O157 can be present on raw meat); know3 (*E. coli* O157 can be present in raw milk); know4 (*E. coli* O157 may contaminate rural drinking water); know5 (*E. coli* O157 may contaminate produce such as lettuce, apples, spinach)	1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree
effect	Perceived effects on the way of managing business during the past 5 years effect1 (reports of *E. coli* O157 outbreaks or incidents); effect2 (experience of *E. coli* O157 outbreaks or incidents); effect3 (incidents of *E. coli* O157 that occurred on own farm)	1 = not affected; 2 = slightly affected; 3 = much affected
biosec	Perceived practicality of biosecurity measures on farm biosec1 (cleaning water troughs daily); biosec2 (disinfecting the animal sheds/pens weekly); biosec3 (applying slaked lime to animal bedding every 3 weeks)	1 = not at all practical; 2 = of little practicality; 3 = moderately practical; 4 = practical; 5 = very practical
benefit	benefit1 (who do you think would benefit the most from on-farm controls to reduce *E. coli* O157 in cattle?)	0 = otherwise; 1 = farm owners
respons	respons1 (who do you think is responsible for controlling *E. coli* O157 on farms?)	0 = otherwise; 1 = farm owners
attitude	attid1 (if you used control measures for *E. coli* O157 in cattle on-farm the price for your produce might increase); attid2 (if you used control measures for *E. coli* O157 in cattle on-farm it would enhance reputation with customers)	1 = strongly disagree; 2 = disagree; 3 = neither agree nor disagree; 4 = agree; 5 = strongly agree
wtpmoney	wtp1 (willingness to pay money per animal per year to ensure that *E. coli* O157 is not present on own farm)	1 = nothing; 2, <£1; 3, £1–5; 4, £5–10; 5, >£10
wtptime	wtp2 (willingness to spend time to ensure that *E. coli* O157 is not present on own farm)	1 = none; 2 = 1 day/year; 3 = 30 minutes/month; 4 = 30 minutes/week; 5 = 30 minutes/day
vaccines	Vaccine (willingness to use a treatment such as two doses of vaccine that would cost £5 to buy for each animal every year and be given to cattle aged 3–18 months)	0 = not willing to use this; 1 = willing to use this

The questionnaire was consistent with the aim of testing the research hypotheses and the use of SEM. It included closed-ended questions on the following: socio-demographical information about the farmer (gender, age, education); farm economic information (status with respect to the farm holding, total farm land area, number of livestock, full-time and part-time labour, share of income from livestock production, organic certification, open farm characteristics, proportion of farm income dependent on opening to the public); access to information sources; knowledge about *E. coli* O157; attitudes regarding the use of control measures for *E. coli* O157; perceived benefits of controlling *E. coli* O157; perceived responsibility in controlling *E. coli* O157; influence on business of factors such as regulations and *E. coli* O157 outbreaks; perceived practicality of biosecurity measures; intentions to change farm size; intentions to change public access to the farm; intentions to change *E. coli* O157 control measures on-farm; willingness to use *E. coli* O157 control measures.

Table 1 presents a description of the latent variables and their corresponding indicators included in the SEM model.

The data used in this study was collected through a representative survey of UK cattle farmers. The sampling frame was derived from the June 2010 Survey of Agriculture and Horticulture for England, Wales, Scotland and from the Public Health Information System data for Northern Ireland and included all holdings with cattle. The criteria for inclusion in the study were as follows: main farm type (classification derived from the June survey information as the standard measure of farm activity and type; to be classed in a particular area, a holding must have at least two-thirds of its activity in one particular area, otherwise it is deemed to be of mixed type); farm size [using only holdings which have a standard labour requirement (SLR) >0·25 FTE (full time equivalent) to avoid inclusion of hobby farmers]; stocking density or less favoured area (LFA) marker (used in place of stocking density when data is not available); livestock groups (holdings can either have dairy and/or beef – any one activity or all); region (England, Wales, Scotland, Northern Ireland).

A stratified sample was drawn from this population in which the sample had the same proportionate split of holdings according to farm type. Farmers were removed from the sample if they met any of the following criteria: they were no longer active on the register (ceased farming); they were listed as a 'stop' (people to whom no correspondence was sent, e.g. recent bereavements).

During the 3 weeks prior to the survey (April 2011), 1420 opt-out letters were sent to farmers in England, Scotland, Wales and Northern Ireland. The opt-out letter stated the aim of the survey, approximate duration of the interview, underlined that the survey was voluntary and that it ensured respondent anonymity. The letters sent to the Welsh farmers were in both English and Welsh. Farmers who did not wish to participate were asked to return an enclosed form in a reply paid envelope provided, within 1 week. We allowed 2–3 weeks for opt-out letters to be returned by farmers before the survey started, and 81% of the farmers contacted by postal mail (opt-out letter stage) did not return their opt-out letters and implicitly agreed to participate in the telephone interview.

A pilot survey of 10 farmers from England, Scotland, Wales and Northern Ireland was conducted to identify any changes needed to the questionnaire before administration.

The telephone survey took place during May–June 2011. Overall, 405 farmers were contacted by telephone for the interview. The average duration of the interview was 17 minutes. The interviews were not audio-recorded but notes were taken by the interviewer and answers compiled in an SPSS database. Farmers were reassured that all information provided would be completely anonymous in any subsequent reports or publications and that they and their farms would never be individually identifiable. Any farmers wishing to opt out after the data was collected were able to do so.

RESULTS

Descriptive statistics for the sample

A total of 405 completed questionnaires were obtained forming a representative sample at the UK level (147 England, 123 Wales, 101 Scotland and 34 Northern Ireland; 309 beef and 96 dairy cattle farms). The total sample size of 405 farmers is consistent with methodological requirements (estimation method and number of measured parameters).

Regarding socio-economic characteristics, the sample consisted of 85% male farmers and 15% female farmers. Age distribution showed 38% of farmers aged <50 years, 40% between 51–65 years and 22% >65 years. For educational level, 45% of farmers finished school, 42% finished college and 12% finished university. With respect to farm holding, most farmers (61%) owned their farms, 25% were partly tenants/partly owners and 12% were tenants. About two thirds of farmers (63%) used an animal health plan to manage the health of their livestock. Regarding income, 75% of farmers had half or more of their income coming from livestock production and only about 5% of farmers had more than 5% of their income dependent on opening their farm to the public.

Regarding knowledge about the impact of *E. coli* O157 on human health, the majority of farmers were aware that *E. coli* O157 causes disease in people (82%), that people touching calves/cows may become infected with *E. coli* O157 (73%), that livestock were an important source from which *E. coli* O157 spreads (62%) and that *E. coli* O157 could be present on raw meat (76%), in raw milk (49%) and could contaminate produce such as lettuce, apples, spinach (51%) or rural drinking water (54%)†. The survey also identified a number of farmers that demonstrated a lack of awareness of the different potential means of *E. coli* O157 transmission, which might imply that not all farmers implemented the necessary controls to prevent cross-contamination.

With regard to sources of useful information on *E. coli* O157, 79% of farmers stated media, followed by veterinary surgeons (44%), government (33%), other farmers (23%), industry organizations (19%) and the internet (6%)†.

As regards perceived beneficiaries of on-farm controls to reduce *E. coli* O157 in cattle, 75% of farmers answered that all (farmers, processors, retailers, public, government) would benefit. Regarding perceived responsibility for controlling *E. coli* O157 on farms, 66% of farmers stated that responsibility remained with them; however, 21% of farmers stated that all should share responsibility and 12% of farmers considered that the government should be responsible for the control of *E. coli* O157 on-farms. Only around 19% of farmers agreed that *E. coli* O157 might be present in cattle on their farm, including 3% who strongly agreed with this statement.

With respect to *E. coli* O157 on farm control, the majority of farmers found as practical/very practical the following biosecurity measures: separating animals into different age groups for the majority of the time (74%), keeping bedding dry and replacing contaminated/wet bedding on a daily basis (65%), quarantine and testing of livestock brought to the farm (57%) and cleaning feed troughs daily (54%). Reducing current livestock numbers on the farm and disinfecting the animal sheds/pens weekly were found to be not at all practical by 44% and 40% of farmers, respectively.

Regarding willingness to control *E. coli* O157 on farm, a low majority of farmers (59%) stated they would be willing to use a treatment such as two doses of vaccine that would cost £5 to buy for each animal every year and given to cattle aged 3–18 months. For the majority (91%) of the farmers not willing to use vaccination, one of the reasons was lack of information, for 69% of farmers the cost was too expensive, while 49% said that it would take too much time to administer. However, 61% of farmers said that they would be encouraged to use vaccination if it was part of a national programme to benefit the reputation of the industry, while 44% of farmers stated they would be encouraged to use vaccination if it was used by other farmers. Additional reasons given by farmers against vaccination were the need for clear evidence of disease, regulation related ('if it was obligatory') and practical difficulties relating to the implementation of the vaccine.

While almost half of the farmers (47%) indicated that they would be willing to pay £1–5 and a seventh of farmers (14%) more than £5 per animal per year to ensure that *E. coli* O157 was not present on their own farm, almost a sixth (17%) of farmers answered that they would not be willing to spend any money. A ninth (11%) of farmers would be willing to spend time on a daily basis (30 minutes per day) to ensure that *E. coli* O157 was not present on their own farm; however, about a fifth (18%) would not spend more than 1 day per year and about an eighth (12%) of farmers would not be willing to spend any time at all.

Table 2 presents some descriptive statistics for the variables included in the model.

Results of the SEM

The path diagram for the estimated SEM is presented in Figure 1.

The model has a good fit according to the measures of absolute, incremental and parsimonious fit. The main GoF indicators (estimated and recommended values) for the estimated models are presented in Table 3.

Additional testing of the appropriateness of the model was achieved by comparing the estimated model with two other models that acted as alternative explanations to the proposed model in a competing models strategy using a nested model approach. The results across all types of GoF measures favoured the estimated model in most cases. Therefore, we confirmed the accuracy of the proposed model and discarded the competing ones.

In the measurement model we tested the reliability of the single-indicator latent variables using the 'theory-testing extremes' of reliability within the range of 0·7–1 and determined that none of the structural coefficients became non-significant at these extremes.

After assessing the overall model and aspects of the measurement model, the standardized structural coefficients for both practical and theoretical implications were examined. Table 4 presents the standardized total effects between the latent variables in the model.

† The percentages relate only to those farmers who had heard of *E. coli* O157 prior to the survey (73% of the total sample).

Table 2. *Descriptive statistics*

Latent variables	Indicators	Cronbach alpha	Mean	S.D	Skewness	Kurtosis
farmtype	type	–	1·76	0·426	−1·241	−0·461
hplan	health	–	1·27	0·960	−0·567	−1·679
income	open	–	1·06	0·271	5·227	29·024
info	info1	0·655	1·63	0·554	−1·194	0·445
	info2		0·84	0·763	0·270	−1·239
	info3		0·90	0·665	0·116	−0·747
	info4		1·70	0·515	−1·455	1·179
	info5		1·15	0·749	−0·244	−1·183
	info6		1·05	0·764	−0·079	−1·282
know	know1	0·781	3·83	1·011	−0·890	0·372
	know2		4·23	0·759	−1·135	2·265
	know3		3·83	0·972	−0·892	0·556
	know4		3·75	1·074	−0·983	0·393
	know5		3·87	1·058	−1·067	0·681
effect	effect1	0·825	1·14	0·417	3·148	9·524
	effect2		1·10	0·359	3·883	15·200
	effect3		1·11	0·389	3·775	13·903
biosec	biosec1	0·510	2·91	1·421	0·103	−1·310
	biosec2		2·18	1·291	0·858	−0·409
	biosec3		3·23	1·352	−0·300	−1·148
benefit	benefit1	–	0·14	0·351	2·045	2·192
response	respons1	–	0·66	0·474	−0·686	−1·537
attitude	attid1	0·579	2·80	1·239	0·181	−1·093
	attid2		3·41	1·227	−0·497	−0·804
wtpmoney	wtp1	–	2·67	1·037	−0·050	−0·276
wtptime	wtp2	–	3·06	1·205	−0·159	−0·896
vaccines	vaccine	–	0·59	0·493	−0·347	−1·889

S.D., Standard deviation.

Behavioural willingness (i.e. willingness to spend time to control *E. coli* O157 on farm; willingness to pay money to control *E. coli* O157 on farm; willingness to use vaccination to control *E. coli* O157 on farm) is significantly influenced by perceptions of farmers being most responsible for *E. coli* O157 on-farm control; attitudes towards *E. coli* O157 on-farm control; proportion of farm income dependent on opening to the public; and perceived effects of *E. coli* O157 on business. Additionally, willingness to pay money or vaccinate are significantly influenced by frequency of access to information and knowledge about *E. coli* O157, while willingness to spend time to control the disease is influenced by perceived practicality of biosecurity measures for *E. coli* O157 on-farm control; use of a health plan; perceptions of farmers as main beneficiaries of *E. coli* O157 on-farm control; and farm type.

The model has a good level of prediction as it explains more than half (52% and 76%) of the variance in willingness to pay money and, respectively, willingness to use vaccination to ensure that *E. coli* O157 is not present on their own farm. A lower but still significant level of prediction (42%) is shown for willingness to spend time to control *E. coli* O157 on farm.

Of the factors influencing all behavioural willingness variables, the highest effect is shown by the perceptions of farmers being most responsible for *E. coli* O157 on-farm control (50%, 36% and 50% *ceteris paribus* on willingness to spend time, money and vaccinate, respectively). This suggests that farmers who feel responsible towards controlling *E. coli* O157 on-farm control are more likely to be willing to use control measures. The variable has a direct impact on willingness to vaccinate and, through it, an indirect impact on willingness to spend money to control the disease (Fig. 1). Its impact on willingness to spend time to control the disease is both direct and indirect through use of a health plan (Fig. 1). The latter implies that responsibility towards disease control influences a farm's adoption of an animal health plan.

Farmers' attitudes towards *E. coli* O157 on-farm control is another main factor influencing all

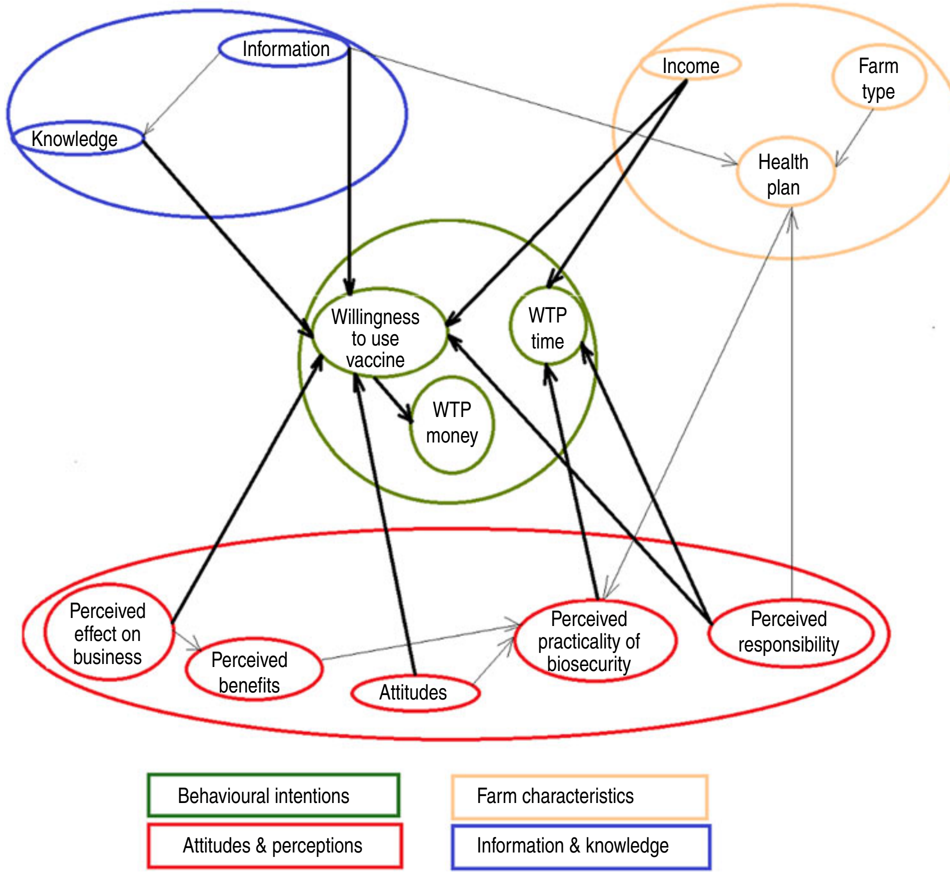

Fig. 1. Conceptual path diagram for the estimated model showing the drivers of farmers' behavioural intentions towards *Escherichia coli* O157 on-farm control. The arrows indicate direction of influence of each latent variable on another; thick bold arrows represent direct influences on behavioural intentions; thin bold arrows represent indirect influences on behavioural intentions. WTP, Willingness to pay.

behavioural willingness variables (14%, 31% and 42% *ceteris paribus* on willingness to spend time, money and vaccinate, respectively). The variable has a direct impact on willingness to vaccinate and, through it, an indirect impact on willingness to spend money to control the disease (Fig. 1). Its impact on willingness to spend time to control the disease is indirect through perceptions of biosecurity practicality (Fig. 1). This confirms one of the main facts of behavioural theories, namely that attitudes precede intentions and behaviour. Farmers with stronger attitudes towards *E. coli* O157 control are more likely to have stronger perceptions of the practicality of control measures and be willing to control the disease.

Another main influence on behavioural willingness is the proportion of farm income dependent on opening to the public (34%, 26% and 37% *ceteris paribus* on willingness to spend time, money and vaccinate, respectively). The variable has a direct impact on willingness to spend time to control the disease and on willingness to vaccinate and, through the latter, an indirect impact on willingness to spend money to control the disease (Fig. 1). This suggests that farmers whose income depends more on opening their farms to public are more likely to be willing to vaccinate or spend more money/time to control *E. coli* O157.

Perceived effect of reports/experience/incidents of *E. coli* O157 outbreaks or incidents on the way of managing business during the past 5 years has a significant influence on behavioural willingness (4%, 24% and 33% *ceteris paribus* on willingness to spend time, money and vaccinate, respectively). This suggests that farmers whose livestock was affected by disease in the past or who know other farmers affected by it are more likely to be willing to control the disease. There is a large difference between the impact on willingness to spend time and the impact on willingness to vaccinate/spend money to control disease, which may suggest that farmers affected by *E. coli* O157 in the past consider vaccination as more effective than

Table 3. *Goodness-of-fit indicators*

Goodness-of-fit indicators	Estimated value	Recommended value
Degrees of freedom	314	–
Satorra–Bentler Scaled χ^2	597·29	–
Normed χ^2 (df)	1·9	[1–3]
Root mean square error of approximation (RMSEA)	0·071	0·00–0·10
Goodness of fit index (GFI)	0·90	0·90–1·00
Normed fit index (NFI)	0·90	0·90–1·00
Non-normed fit index (NNFI)	0·95	0·90–1·00
Comparative fit index (CFI)	0·95	0·90–1·00
Incremental fit index (IFI)	0·95	0·90–1·00

The table presents absolute, incremental and parsimonious goodness-of-fit indicators. The absolute fit indicators include: root mean square error of approximation and goodness of fit index. Incremental fit indicators include: adjusted goodness of fit index, non-normed fit index, normed fit index, relative fit index, comparative fit index and incremental fit index. Parsimonious fit indicators include normed χ^2.

Table 4. *Standardized total (direct and indirect) effects (t values in parentheses)*

Observed/ latent variables	Total effects on 'wtptime'	Total effects on 'wtpmoney'	Total effects on 'vaccines'
farmtype	−0·05 (−2·46)	–	–
hplan	0·09 (2·69)	–	–
income	0·34 (2·41)	0·26 (2·01)	0·37 (2·03)
info	0·02 (1·85)	0·13 (2·82)	0·18 (2·78)
know	–	0·12 (2·96)	0·16 (2·96)
effect	0·04 (2·33)	0·24 (6·58)	0·33 (6·81)
biosec	0·27 (3·44)	–	–
benefit	0·09 (2·66)	–	–
respons	0·50 (4·20)	0·36 (3·95)	0·50 (4·14)
attitude	0·14 (2·77)	0·31 (5·59)	0·42 (5·71)
vaccines	–	0·72 (12·69)	–
R^2	0·42	0·52	0·76

The latent variable scores and observational residuals depend on the unit of measurement in the observed variables. As some of these units are the result of subjective scaling of the observed variables the observational residuals were standardized (rescaled such that they have zero means and unit standard deviations in the sample) [22]. Total effects represent how much a 1-unit change in an independent variable will change the expected value of a dependent variable.

other less-expensive but more time-consuming measures. The variable has a direct impact on willingness to vaccinate and, through it, an indirect one on willingness to spend money to control the disease (Fig. 1). Its impact on willingness to spend time to control the disease is indirect through perceptions of farmers as main beneficiaries of *E. coli* O157 on-farm control (Fig. 1). The latter might suggest that farmers who experienced the impact of disease are more likely to be aware of the benefits of controlling it.

Besides the four factors above influencing all behavioural willingness variables, willingness to vaccinate or spend money to control the disease are also influenced by information and knowledge.

There is a very strong relationship between intention to vaccinate and the more general intention to spend money to control *E. coli* O157 on farm (72% *ceteris paribus*). This suggests that, as vaccination would be an expensive exercise, farmers willing to use it are more likely to be willing to spend money on this and/or other measures of *E. coli* O157 control.

Access to information has a significant influence – directly and indirectly through knowledge (Fig. 1) – on willingness to use vaccination (18% *ceteris paribus*) and, through it, an indirect one on willingness to spend money to control *E. coli* O157 on farm (13% *ceteris paribus*). This suggests that farmers with more frequent access to information are more likely to have knowledge about *E. coli* O157 and be willing to control *E. coli* O157 on farm.

Knowledge about *E. coli* O157 has a significant influence on willingness to use vaccination (16% *ceteris paribus*) and, through it, an indirect one on willingness to spend money to control *E. coli* O157 on farm (12% *ceteris paribus*) (Fig. 1). This supports the scientific evidence on the established linkage between knowledge and behavioural intentions and shows knowledge of *E. coli* O157 as a necessary antecedent of intention to vaccinate or spend money to control *E. coli* O157 on farm.

Willingness to spend time to control *E. coli* O157 on farm is also influenced by perceived practicality of biosecurity, use of a health plan, perceived benefits and farm type. The model included a significant relationship between access to information and use of a health plan (25% *ceteris paribus*); however, this influence did not mediate a significant impact of information on willingness to spend time to control disease (Fig. 1).

Farmers' perceptions of biosecurity measures to be practical/suited to the needs of their farms significantly influence willingness to spend time to control *E. coli* O157 on farm (27% *ceteris paribus*). As the biosecurity measures included in the model are time consuming, farmers' perceptions of their practicality and suitability for the control of *E. coli* O157 on farm would influence their willingness to spend more time in controlling the disease.

Use of a health plan has a lower but significant indirect – through perceptions of biosecurity practicality (Fig. 1) – influence on willingness to spend time to control *E. coli* O157 on farm (9% *ceteris paribus*). This might suggest that farmers using a health plan, which is likely to include biosecurity measures, are more likely to find these measures as suitable to control the disease and, implicitly, be willing to spend more time on disease control.

Perceptions of farmers as the main beneficiaries of *E. coli* O157 on-farm control have a lower but significant indirect – through perceptions of biosecurity practicality (Fig. 1) – influence on willingness to spend time to control *E. coli* O157 on farm (9% *ceteris paribus*). This implies that farmers who think they benefit from disease control are more likely to perceive the practicality of biosecurity measures and, implicitly, be willing to spend more time on disease control.

Farm type has a low but significant influence (5% *ceteris paribus*) on willingness to spend time to control *E. coli* O157 on farm. The effect is indirect through use of a health plan (Fig. 1). This implies that dairy farmers rather than beef farmers are more likely to use a health plan and be willing to spend more time in controlling *E. coli* O157 on farm.

DISCUSSION

The study analysed the impact of *a priori* determinants of adoption of *E. coli* O157 control measures by cattle farmers in the UK. We used a dataset collected through a stratified telephone survey of 405 cattle farmers in the UK and SEM with observed and latent variables to test the influence of *a priori* identified determinants on behavioural intentions towards *E. coli* O157 control.

The results confirm findings from the literature and expert opinion. The model has a good level of prediction as it explains a high percentage of the variance in willingness to control *E. coli* O157 on farm. However, the level of prediction could improve if other factors were added to the model. The literature on farmers' attitudes and behaviour towards control measures of *E. coli* O157 is currently limited. More research is needed, especially of the exploratory type (e.g. using qualitative data from in-depth interviews or focus groups) to identify other factors influencing farmers' behaviour regarding disease control.

The results of this study will contribute to the existing evidence and will potentially assist policy makers in finding means of behavioural change.

The model suggests that farmers more likely to show a higher willingness to control *E. coli* O157 on farm are those: with stronger perceptions of responsibility towards *E. coli* O157 on-farm control [13]; with stronger attitudes towards *E. coli* O157 on-farm control [9, 12, 13]; with higher proportion of the farm income dependent on opening to the public [10, 11]; who were affected by *E. coli* O157 incidents in the past [9, 12, 16–19]; who are more informed and have better knowledge about *E. coli* O157 [12–15]; with stronger perceptions of practicality of biosecurity measures for *E. coli* O157 on-farm control [12, 20]; who use a health plan [9]; with stronger perceptions of benefits of *E. coli* O157 on-farm control [12]; and whose farms are dairy rather than beef.

This might imply that increasing access to information to all farmers and targeting more specifically dairy farmers, farmers who open their farms to public and farmers affected by past outbreaks might lead to better knowledge, stronger perceptions and attitudes and, consequently, higher willingness to control *E. coli* O157 on farm.

The fact that responsibility perceptions were found to have the strongest effect on behavioural willingness to control the disease might suggest the need not only to increase access to information, but to provide information on sources and modes of *E. coli* O157 transmission.

Similarly, the fact that perceived practicality of biosecurity measures was found to have a strong effect on willingness to control the disease might suggest the need to provide information on control measures to suit the specific circumstances of farms.

Farmers' intentions to control *E. coli* O157 on-farm are influenced by their attitudes with regard to potential rewards, such as increase in the price of their products or enhanced reputation with customers if they used control measures. This might suggest that if major retailers and buyers of milk and beef would provide incentives, farmers would be more willing to apply proven *E. coli* O157 on-farm control.

The findings might suggest that farmers may implement on-farm controls for *E. coli* O157 if they identify a clear hazard and if there is greater knowledge of the safety and efficacy of the proposed controls. Despite farmers recognizing a responsibility for the potentially negative consequences that maintaining cattle and spreading this pathogen poses to the public, for the majority of farmers there is a lack of validated on-farm control options, and the lack of a clear link between human cases of infection and their own livestock. This might suggest the need to provide information on safety and efficiency of control options in addition to modes of disease transmission.

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DECLARATION OF INTEREST

None.

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