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Dairy farmers' intention to use calf management technologies in four European countries: A QCA and PLS-SEM approach

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ABSTRACT

Whilst livestock management technologies may help to improve productivity, economic performance, and animal welfare on farms, there has been low uptake of technologies across farming systems and countries. This study aimed to understand dairy farmers' intention to use calf management technologies by combining partial least squares structural equation modelling (PLS-SEM) with qualitative comparative analysis (QCA). We evaluated the hypotheses that dairy farmers will intend to use calf technologies if they have sufficient competencies, sufficient materials, and positive meanings (e.g., attitudes or emotions) towards calf technologies, and they will not intend to use technologies if one of these elements is missing. An online survey was completed by 269 dairy farmers in Belgium, the Netherlands, Norway, and the UK. A PLS-SEM was developed, where the outcome was the number of calf management technologies that the respondent intended to use, and the latent constructs included meanings, materials, and competencies. QCA was then run separately for the datasets from each country. Intention to use technologies was the outcome, whereas positive meanings, sufficient materials, and sufficient competencies for technology use were conditions in the QCA. Evaluation of the PLS-SEM showed that reliability and validity of the latent constructs was appropriate for analysis. Assessment of the structural model indicated that having positive meanings regarding technologies significantly increased the number of calf technologies the farmer intended to use ($\beta = 0.388$, CI = 0.291 – 0.486). The QCA solutions show that the conditions for the intention to use, or not use, calf technologies differed between Belgium, the Netherlands, Norway, and the UK, but the presence (or absence) of positive meanings was consistently important. The solutions for Norway and Belgium aligned with our hypotheses, but the solutions for the Netherlands and UK did not. Some of the solutions exhibited features of causal complexity such as equifinality, conjunctural causation, and asymmetric causation, which would not be able to be easily identified using traditional regression analyses. This study highlights the causal complexity of technology use on farms as a social phenomenon. Furthermore, the study shows the usefulness of QCA for evaluating theoretical hypotheses regarding farmers' behaviour. We suggest that researchers could use this method to investigate other practices on farms that may have causal complexity.

1. Introduction

Dairy farmers are required to make numerous decisions around farm management every day. Livestock management technologies, such as decision support tools, aim to improve the decision-making of farmers and may help to improve productivity, economic performance, animal health and welfare (Cabrera, 2018; Ferris et al., 2020). However, there has been low uptake of livestock management technologies across countries and farming systems (Kaler and Ruston, 2019; Groher et al., 2020). This has led to research that aims to understand the barriers and drivers of technology adoption on dairy farms (Borchers and Bewley, 2015; McDonald et al., 2016; Gargiulo et al., 2018). Most of these studies focus on technologies for management of adult dairy cows, such as automatic milking systems (Gargiulo et al., 2018) and systems to measure cow activity (Silvi et al., 2021; Bianchi et al., 2022). Technologies can also be used for youngstock or calf management, such as sensor

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technology to measure temperature and activity, data capture technologies, and automation technology (e.g., automatic feeders) (Doidge et al., 2024b). The small number of studies that include youngstock or calf management technologies suggest that their uptake is particularly low (Medrano-Galarza et al., 2017; Palma-Molina et al., 2023).

Relatively few studies of technology adoption on dairy farms have used theories or models of technology use in their design (Flett et al., 2004; Rehman et al., 2007; Michels et al., 2019). However, it has been suggested that use of theoretical frameworks can improve the uptake of desired behaviours (Biesheuvel et al., 2021; Reyneke et al., 2023). Previous qualitative research has shown that social practice theory can be a useful lens for understanding technology use and digitalisation of farms (Abdulai, 2022; Doidge et al., 2023b). In social practice theory, the social world is seen as composed of practices and individuals are seen as carriers of a practice. Social practice theory is relevant to technology use on farms for a multitude of reasons. Firstly, previous research shows that multiple practices make up technology use (Doidge et al., 2023b). For example, technologies can be used as part of data collection practices, data interpretation practices, animal care practices or a combination of these practices. Additionally, there is diversity in the ways that farmers implement technologies (Schewe and Stuart, 2015; Doidge et al., 2023a). Social practice theory also acknowledges that sufficient competencies are required for practices to be enacted. Digital skills have been shown to be key for technology adoption and use on farms (Marshall et al., 2022). Finally, social practice theory considers the material requirements of technology use on farms, which may include appropriate infrastructure, support structures, financial resources, and the technologies themselves (Abdulai, 2022; Marshall et al., 2022).

At present, most analyses that use social practice theory to understand social phenomena are based on qualitative or ethnographic research. However, there is an emerging field of research which examines social practices through quantitative methods (Meier et al., 2018; Sonnberger, 2022). Quantitative methods can show how ubiquitous routine practices are across the population in a way that cannot be revealed through qualitative data. For example, Sonnberger (2022) identified six different clusters of sustainability practices, each of them associated with specific sociodemographic features. Studies that explore social practices using quantitative methods tend to use symmetric data analysis techniques such as structural equation modelling (SEM) or multiple linear regression (Hess et al., 2018; Ali, 2021; Sharifzadeh et al., 2023). Whilst these approaches can estimate the effects of variables on an outcome, they overlook the complexity of social phenomena (Papatheodorou and Pappas, 2017), which is apparent when using social practice theory as a lens.

Qualitative comparative analysis (QCA) is a data analysis technique which combines aspects of qualitative methods, such as complexity, logic, and contextual richness, with aspects of quantitative methods, such as dealing with larger datasets and providing greater generalisability (Pappas and Woodside, 2021). QCA is a configurational approach that can model the presence of three features of causal complexity: conjunctural causation, equifinality, and asymmetric causation (Oana et al., 2021). Conjunctural causation is when factors may only have a causal role in combination with other factors. Equifinality is when multiple combinations of conditions can lead to the same outcome. Asymmetric causation is when the conditions that cause an outcome are not a mirror of the conditions that cause the negated outcome. In other words, “presence of a cause leads to presence of the effect, but absence of the cause may not lead to absence of the effect” (Glaesser, 2023). The ability of QCA to model such complexity makes it a potentially useful method for testing social practice theory and understanding the reasons why technologies are used, or not used, on farms.

Theoretical constructs are often measured indirectly with measurement scales (i.e., by asking respondents to rate multiple items/statements). One of the criticisms of QCA is that when including a theoretical construct in the QCA model, researchers tend to compute the sums of items in a scale (Rasoolimanesh et al., 2021). This ignores the measurement error, which leads to reduced reliability and validity of the model. Thus, it is important to evaluate measurement scales prior to being included in QCA (Smith et al., 2023). One method of doing so is to combine QCA with partial least squares structural equation modelling (PLS-SEM) to account for measurement errors in measurement scales (Rasoolimanesh et al., 2021). Therefore, this study aimed to understand the intention to use calf management technologies on dairy farms in Belgium, the Netherlands, Norway, and the UK using a social practice theory lens. To do so, a novel combined PLS-SEM and QCA approach was used.

2. Methods

2.1. Theoretical framework: social practice theory

In this study, we draw on the theoretical framework described by Shove et al. (2012). In their version of social practice theory, a practice will only be performed if links between three elements exist. These elements are called meanings, materials, and competencies (Fig. 1). Materials are things such as infrastructure, the body itself, and technologies. We also suggest that social structures which provide support can be a form of material (Doidge et al., 2023b). Competencies include skills, tacit knowledge, and forms of understanding. Meanings are values, attitudes, motivations, and emotions. If any of these three elements are not present, then the practice will not be performed. This led to the following hypotheses:

1. Farmers will intend to use calf technologies if they have sufficient competencies, sufficient materials, and positive meanings towards calf technologies.
2. Farmers will not intend to use calf technologies if they do not have sufficient competencies, or do not have sufficient materials, or do not have positive meanings towards calf technologies.

3. Ethics

The study was approved by the University of Nottingham School of Veterinary Medicine and Science Ethics Committee (no. 3741 221213). The farmers were informed that participation in the survey was voluntary, and that the data generated would be anonymised and would be used for research purposes. The respondents indicated their consent by selecting tick boxes at the start of the survey.

3.1. Survey design

The survey questionnaire was designed based on the results from focus groups which explored dairy farmers’ perceptions and experiences of calf management technologies from multiple European countries (Doidge et al., 2023a,2024a), including one study which adopted the

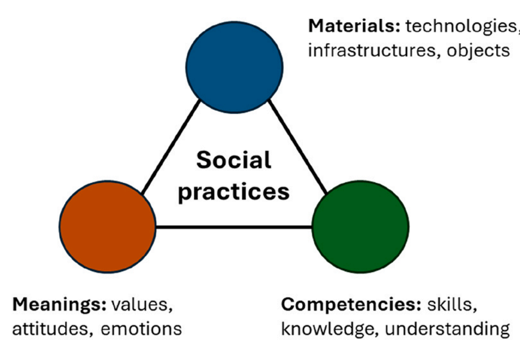

Fig. 1. Elements of social practice theory. Adapted from Shove et al. (2012) and Doidge et al. (2023b) .

social practice lens (Doidge et al., 2023b). The survey was designed in English by CD and JK, with feedback provided by all authors to ensure it was suitable for distribution in different countries. It was then translated into Dutch by the authors JB and NtB, and Norwegian by the authors LPC and PH. The survey was piloted by four farmers in the UK and five farmers in Belgium. The survey took approximately 15–20 minutes to complete. An overview of the survey questions that are relevant to this study is provided in the following sections and a copy of the survey is available in the Supplementary material.

3.1.1. Farmer and farm characteristics

This section included questions on the farmers' characteristics such as age, number of years working in the dairy industry and gender. The farm characteristics included questions such as calving pattern, number of calves and adult dairy cows in 2022 and number of people employed on the farm.

3.1.2. Data and technology

Respondents were asked to select which information they routinely collected about their calves. They could select from: weights, solid feed intake, milk intake, water intake, temperature, medicine records, and activity. If they did record information, then they were also asked how they recorded information (e.g., electronically or paper based) and how often they recorded the information.

The respondents were asked to select which technologies relating to calf management they currently used on their farm from the following list: automatic feeding system, milk taxi, temperature monitors (e.g., ear tags, boluses), activity monitor, weighing scales, EID readers, and cameras. Then, they were asked which of these technologies they intended to use in the next 24 months. The wording of this question allowed farmers to select both technologies they currently used and intended to continue using in the future, and technologies they have not used before but intended to use in the future.

Table 1
Items included in the survey, their direction of effect, and the social practice theory elements that they were intended to represent.

Item (direction of effect)	Element
Q1: Using calf management technologies is important for the future of my farm (positive)	Meaning
Q2: Adoption of calf management technology on farms is expensive (negative)	Material
Q3: Calf management technologies can make my life easier (positive)	Meaning
Q4: I prefer to work with my calves rather than sitting at a computer (negative)	Meaning
Q5: Using calf management technologies takes up a lot of time (negative)	Meaning
Q6: Calf management technologies generate useful outputs (positive)	Meaning
Q7: I find calf management technologies difficult to use (negative)	Competencies
Q8: It is easier to collect data without using calf management technologies (negative)	Competencies
Q9: I have the skills required to use calf management technologies (positive)	Competencies
Q10: Calf management technologies can provide me with a better work-life balance (positive)	Meaning
Q11: My farm has the appropriate infrastructure (e.g., internet, electricity) for using calf management technologies (positive)	Material
Q12: I have the support I need to use calf management technologies (positive)	Material
Q13: It is unnecessary for me to use calf management technologies on my farm (negative)	Meaning
Q14: Using calf management technologies is boring (negative)	Meaning
Q15: The size of my farm is not suited towards calf management technologies (negative)	Meaning
Q16: My farming system is not suited towards calf management technologies (negative)	Meaning
Q17: Learning how to use calf management technologies is time consuming (negative)	Competencies

In the final part of this section, respondents were asked to rate a series of 17 statements (Table 1) relating to calf health management using a 5-point Likert scale from strongly disagree to strongly agree. These statements aimed to reflect the three elements of social practice theory: materials, meanings, and competencies (Doidge et al., 2023b).

3.2. Study sample

In the UK the survey was distributed by a specialist fieldwork company with an online panel of dairy farmers. We took this approach as we had previously experienced problems with "bot" respondents. The survey was open from 19th July to 27th July 2023 and each respondent received £ 10 for completing the survey.

In Belgium the survey was distributed by the Animal Health Care Flanders via direct mailings to the farmers, a newsletter, and on the website. Next to this, the survey was shared on social media in specific groups for farmers. The survey was open between the 15th of February to the 3rd of May 2023. As an incentive to participate and finish the survey, three calf blankets were raffled among the participants.

In the Netherlands the survey was communicated by Royal GD through a news item that was included in a newsletter that was distributed to all ~13,000 dairy farmers. The survey was further advertised on the GD website and on social media between 20th February and 15th June 2023. It total five calf blankets were allotted between the participants that finished the survey as incentive to participate.

In Norway a random sample of 600 dairy farmers were contacted by email. In addition, the Communications department of the Norwegian Veterinary Institute shared the survey on social media in groups dedicated to dairy farming. Participants were incentivized to participate trough an economic reward: three vouchers of 500 NOK were drawn by the participants. The survey was open between the 4th of April and the 16th of May 2023.

The suitability of the sample size for PLS-SEM was calculated using the inverse square root method (Kock and Hadaya, 2018). A sample size of 269 could detect a significant effect size for a minimum path coefficient magnitude of 0.15 with power of 0.8. QCA was originally designed for analysis of small- to intermediate-N samples, and 12 cases is the suggested minimum sample size (Fainshmidt et al., 2020).

3.3. Data analysis

All data were translated into English. Data cleaning and descriptive statistics were conducted in Stata 18 (Stata SE/18.0, Stata Corp., College Station, TX, USA). One-way ANOVA tests were conducted to identify significant differences in ratings of the seventeen statements between countries (Norman, 2010).

3.3.1. Exploratory factor analysis

As the items had not been used in previous research, exploratory factor analysis was conducted prior to PLS-SEM to identify which items should be retained for each element (materials, competencies, and meanings). The exploratory factor analysis was run in in Stata 18 (Stata SE/18.0, Stata Corp., College Station, TX, USA), using the method as described in Smith et al. (2023).

3.3.2. PLS-SEM

The PLS-SEM was conducted in R (version 4.2.1) using the 'seminr' package (Hair et al., 2021) following the recommendations of Hair et al. (2019). PLS-SEM was conducted because we (1) wanted to test the social practice theoretical framework, (2) had a relatively small sample size, and (3) required latent variable scores for follow-up analyses (i.e. QCA) (Hair et al., 2019).

The outcome was the number of calf management technologies that the respondent intended to use (ranging from 0 to 5). Meanings, materials, and competencies were latent constructs which were made up of reflective indicators. Based on the results of the factor analysis, the items used as reflective indicators for the Meanings construct were Q1, Q3, Q6, Q10 and reverse coded Q13 and Q14. The items used as reflective indicators for the Materials construct were Q11 and Q12. The items used for the Competencies construct were Q9 and reverse coded Q7 and Q8.

The PLS-SEM has a measurement model and a structural model. We evaluated the measurement model by assessing internal consistency reliability, which is the consistency of people's responses across the items. The internal consistency values can range from 0 to 1, where higher values indicate higher internal consistency. We used a cutoff value of 0.6 as this was exploratory study that did not use pre-existing scales (Hair et al., 2019). Three different measures of internal consistency reliability were calculated in this study: Crohnbach's alpha, Rho C (composite reliability), and Rho A. We also evaluated the convergent validity of each construct measure in the measurement model using average variance extracted (AVE) for all items on each construct. The AVE should be above 0.5 for acceptable convergent validity, as this means that the construct explains more than 50 % of the variance of its items. The heterotrait–monotrait ratio (HTMT) of correlations was used to assess discriminant validity, which is the extent to which a construct is not related to other constructs in the structural model. HTMT values should not be above 0.9. Bootstrapped confidence intervals were calculated for the HTMT to test if the HTMT values were significantly lower than 0.9 (Hair et al., 2021).

We evaluated the structural model by calculating Variance Inflation Factor (VIF) values to determine whether there were collinearity problems. The significance of the path coefficients and relevance of the path coefficients were also evaluated. R^2 was calculated to assess the model's in-sample explanatory power. The model's out-of-sample predictive power was assessed by the $PLS_{predict}$ procedure (Hair et al., 2021). The prediction error was assessed by comparing the mean absolute error (MAE) of the structural model predictions to a naïve linear regression model (LM) benchmark.

3.3.3. Fuzzy set QCA

The QCA was conducted in R (version 4.2.1) using the SetMethods package (Oana et al., 2021). QCA were run separately for the respondents in each country. This is because QCA can be conducted with smaller samples ($n < 12$) and separating by country could generate more nuanced results (e.g., in case of cultural differences).

QCA is a set theoretic method where we analyse social phenomena as sets using Boolean algebra. In Boolean algebra, ~ represents absence of a condition, * represents the logical AND function, and + represents the logical OR function. In Boolean terms, our previously described hypothesis 1 can therefore be described as:

$$\text{MEANINGS} * \text{MATERIALS} * \text{COMPETENCIES} \rightarrow \text{INTTECH}$$

Where presence of positive meanings (MEANINGS) AND sufficient materials (MATERIALS) AND sufficient competencies (COMPETENCIES) regarding calf technologies will lead to the outcome of intending to use calf technologies (INTTECH).

Hypothesis 2 can be described as:

$$\sim \text{MEANINGS} + \sim \text{MATERIALS} + \sim \text{COMPETENCIES} \rightarrow \sim \text{INTTECH}$$

Where absence of positive meanings (~MEANINGS) OR sufficient materials (~MATERIALS) OR sufficient competencies (~COMPETENCIES) regarding calf technologies will lead to the outcome of not intending to use calf technologies (~INTTECH).

Each respondent in the survey was classed as a case, which has membership to sets. Each case can be classed as fully in the set, fully out the set, or a certain degree of belonging in or out of the set. The case membership to a set will always be a value from 0 to 1. In QCA, we use conditions instead of variables/factors. An example of a condition could be "Holstein", whereas the corresponding variable would be "Breed" (Pappas and Woodside, 2021). Membership to a set therefore indicates the presence of a condition.

First, the data were transformed into crisp sets and fuzzy sets. Crisp sets are where variables were dichotomous and fuzzy sets are where variables were continuous. Given that 20 % of the farmers intended to use more than one technology, the data were transformed into having a dichotomous outcome, where 1 = intended to use a calf technology (i.e., fully in the set) and 0 = did not intend to use a calf technology (i.e., fully out the set). Therefore, the outcome was transformed to a crisp set.

Positive meanings, sufficient materials, and sufficient competencies for technology use were conditions in the analysis. The constructs of Meanings, Materials, and Competencies were transformed into fuzzy sets. The standardised latent variable scores from the PLS-SEM were extracted for this purpose (Rasoolimanesh et al., 2021). The standardised latent variable scores were calibrated so that scores were set between −0.5 (i.e., no set membership) and 0.5 (full set membership), whereby 0 was the crossover point.

3.3.3.1. Necessary conditions. The data were analysed to identify any necessary conditions for the intention to use calf technologies. This means that we were looking to satisfy the following equation:

$$X \leftarrow Y$$

Where X (condition) is necessary for Y (outcome). This means that whenever outcome Y is present, condition X is always present (i.e., X is a superset of Y) (Fig. 2). The parameters of fit for the necessity of single necessary conditions and necessary combinations of conditions were calculated for both the outcome and negated outcome. The parameters of fit that were used were: consistency, coverage, and Relevance of Necessity (RoN), which are all given values between 0 and 1. Consistency needs to be over 0.9 to be considered a necessary condition (Oana et al., 2021). The necessary conditions analysis for each QCA is provided in the Supplementary Material.

3.3.3.2. Sufficient conditions. Sufficient conditions are when condition X is present, outcome Y is always present (i.e., X is a subset of Y) (Fig. 2). For the analysis of sufficient conditions, a truth table was constructed for the outcome and negated outcome. Each row in the truth table displays a configuration of the three conditions, where 1 = presence of the condition and 0 = absence of the condition. Each truth table row also shows the number of cases that have membership in that configuration. Each case can only belong to one configuration. Furthermore, the truth table shows whether the configuration is sufficient to reach the outcome, which is determined by a consistency threshold. The truth table for each QCA is provided in the Supplementary Material. A consistency threshold of 0.75 and a frequency threshold of 2 was used for all analyses (Pappas and Woodside, 2021). Logical minimisation of the truth table was conducted to produce the initial QCA solution, which is the formula written in Boolean terms. All possible combinations of conditions were covered by cases in the truth table for each analysis. This means that there were

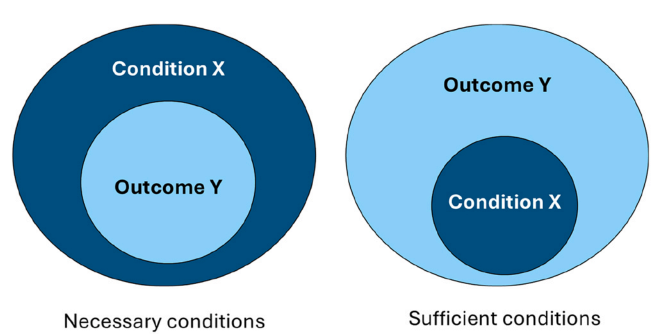

Fig. 2. Example of a necessary condition, in which the condition is a superset of the outcome, and a sufficient condition, in which the condition is a subset of the outcome.

no logical remainders (Oana et al., 2021). The coverage of the initial solution was calculated, which is equivalent to the R^2 reported on regression-based methods (Pappas and Woodside, 2021).

3.3.3.3. Model assessment. We assessed the QCA models for robustness using the Robustness Test Protocol (Oana and Schneider, 2021; Oana et al., 2021), which evaluated sensitivity ranges, fit-oriented robustness, and case-oriented robustness. Sensitivity ranges were calculated for each latent construct, the consistency cutoff, and the frequency cutoff. For the assessment of robustness, the initial solution was compared with three test solutions. The initial solution had a raw consistency threshold of 0.75, a frequency cut off of 2 and the calibration threshold for the meanings construct was set to −0.5 (no set membership), 0 (crossover point) and 0.5 (full set membership). In the test solution 1, the raw consistency threshold was altered to be 0.8 or 0.7, depending on the results from the sensitivity analysis. In the test solution 2, the calibration threshold for the meanings construct was set to −0.25 (no set membership), 0 (crossover point) and 0.25 (full set membership). In the test solution 3, both the consistency threshold and calibration threshold were altered. The test solutions were aggregated to produce a $_{min}$TS (the area on which all alternative solutions agree) and $_{max}$TS (entire area of possible solutions) (Oana and Schneider, 2021). The robust core (RC) was determined by intersecting the initial solution and all the alternative test solutions. To assess fit-oriented robustness, the RC was compared with the initial solution. The parameters of RF_{cov}, RF_{cons}, RF_{SC_minTS}, RF_{SC_maxTS} were calculated, where values range from 0 to 1, and higher values suggest higher robustness.

To assess case-oriented robustness, the case membership for the initial solution was plotted against the case membership in $_{min}$TS/ $_{max}$TS. Case oriented robustness was also assessed by three parameters: the robustness case ratio for typical cases (RCR_{typ}), the robustness case ratio for deviant cases (RCR_{dev}), and the robustness case rank (RCR_{rank}). The RCR_{typ} and RCR_{dev} have values between 0 and 1, where 1 is most robust. The RCR_{rank} produces values of 1, 2, 3, and 4, where 1 is the best situation and 4 is the worst situation in terms of case-oriented robustness. For more detail on the equations used to produce the robustness parameters, see Oana and Schneider (2021). The model assessment parameters for each QCA are displayed in the Supplementary Material.

4. Results

4.1. Respondent and farm demographics

Of the 269 respondents, there were 52 respondents from Belgium, 61 from the Netherlands, 106 from Norway, and 50 from the UK. Table 2 shows the respondent and farm characteristics split by country. Overall, the median number of years working in the dairy industry was 23 (IQR: 12 – 35). Sixty-seven percent of farmers were male (n = 180), 32 % (n = 86) were female, and 1 % (n = 3) preferred not to say.

4.2. Use of, and intention to use, calf management technologies

Overall, 45 % (122/269) of dairy farmers used at least one calf management technology. Fig. 3 shows the number of farmers using calf management technologies in each country. Automatic feeders were the most used technology in the Netherlands (16/61) and Norway (26/106). Milk taxis were the most used technology in Belgium (17/52), and weighing scales were the most used technology in the UK (17/50). In total, 62 % (32/52) of farmers in Belgium, 57 % (35/61) in the Netherlands, 54 % (57/106) in Norway and 46 % (23/50) in the UK did not use any of the seven calf management technologies that were investigated.

Fig. 4 shows the number farmers that intended to use of calf management technologies in the 24 months following survey completion. Of the surveyed population of dairy farmers, 60 % (108/269) intended to use at least one calf management technology in the 24 months following survey completion. In total, 81 % (42/52) of farmers in Belgium, 72 % (44/61) of farmers in the Netherlands, 52 % (55/106) of farmers in Norway and 40 % (20/50) of farmers in the UK intended to not use any of the seven calf management technologies in the following 24 months after survey completion.

Table 3 shows the mean rating in each country for each of the

Table 2
Farm and respondent characteristics by country (BE = Belgium, NE = Netherlands, NO = Norway, UK = United Kingdom).

	BE (n = 52)	NE (n = 61)	NO (n = 106)	UK (n = 50)	All (n = 269)
Age					
30 or under	7 (13 %)	6 (10 %)	10 (9 %)	5 (10 %)	28 (10 %)
31–40	12 (23 %)	14 (23 %)	23 (22 %)	16 (32 %)	65 (24 %)
41–50	14 (27 %)	14 (23 %)	32 (30 %)	14 (28 %)	74 (28 %)
51–60	17 (33 %)	16 (26 %)	21 (20 %)	10 (20 %)	64 (24 %)
61 +	2 (4 %)	11 (18 %)	20 (19 %)	5 (10 %)	38 (14 %)
Gender					
Male	37 (71 %)	45 (74 %)	73 (69 %)	25 (50 %)	180 (67 %)
Female	15 (29 %)	16 (26 %)	31 (29 %)	24 (48 %)	86 (32 %)
Prefer not to say	0 (0 %)	0 (0 %)	2 (2 %)	1 (2 %)	3 (1 %)
Calving pattern					
All year round	45 (87 %)	59 (97 %)	70 (66 %)	36 (72 %)	210 (78 %)
Autumn block	5 (10 %)	0 (0 %)	19 (18 %)	5 (10 %)	29 (11 %)
Spring block	0 (0 %)	0 (0 %)	7 (7 %)	6 (12 %)	12 (4 %)
Multi block	1 (2 %)	1 (2 %)	10 (9 %)	3 (6 %)	15 (6 %)
Other	1 (2 %)	1 (2 %)	0 (0 %)	0 (0 %)	2 (1 %)
	Median (IQR)				
Years working in dairy industry	24 (11 – 32)	30 (20 – 40)	20 (8 – 32)	20 (13 – 30)	23 (12 – 35)
Average N dairy cows in 2022	120 (80–166)	113 (60–160)	32 (20 – 45)	121 (89–260)	75 (35 – 130)
Average N calves in 2022	50 (30 – 94)	38 (20–75)	40 (24 – 58)	100 (75 – 176)	50 (27 – 80)
N full time staff	2 (1–2)	1 (1 – 2)	1 (1 – 2)	2 (2 – 4)	1 (1 – 2)
N part time staff	1 (0 – 1)	1 (0 – 1)	1 (1 – 2)	1 (0 – 2)	1 (0 – 2)
Average vet visits per month (routine and emergency)	3 (2 – 4)	2 (1 – 3)	3 (2 – 6)	2 (1 – 3)	2 (1 – 4)

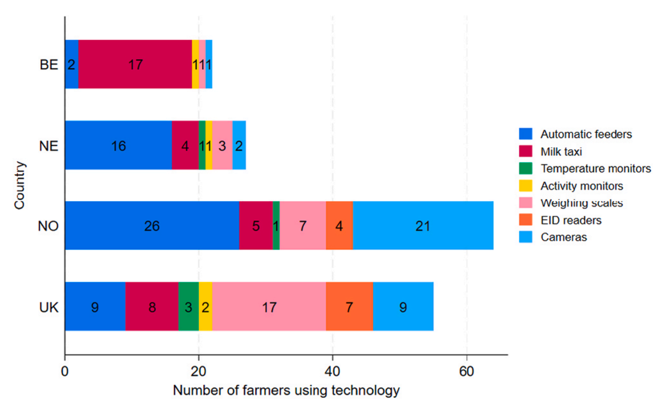

Fig. 3. Number of farmers that used technologies for calf management at the time of survey completion. (BE = Belgium, NE = Netherlands, NO = Norway, UK = United Kingdom).

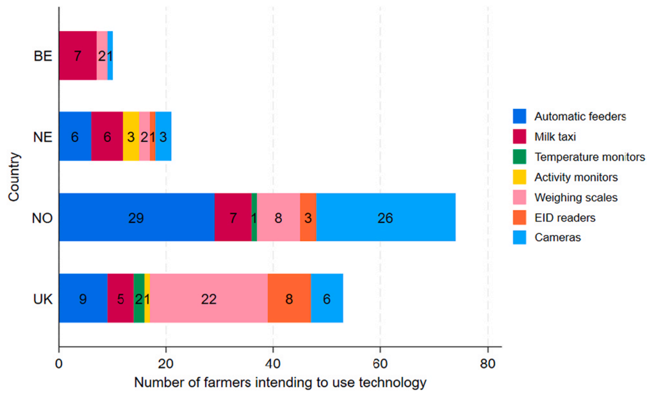

Fig. 4. Number of farmers that intended to use technologies for calf management in the 24 months following survey completion. (BE = Belgium, NE = Netherlands, NO = Norway, UK = United Kingdom).

statements regarding perceptions towards calf management technologies.

4.3. PLS-SEM

4.3.1. Measurement model reliability and validity

Table 4 shows the metrics necessary to evaluate the construct measures' reliability. The values for the Cronbach's alpha, Rho C and Rho A suggested that the internal consistency reliability was sufficient for analysis. The AVE was above 0.5 for each construct, which suggested that convergent validity was acceptable (Table 6). The 90 % bootstrapped confidence intervals for the HTMT values were always below 0.9, (Supplementary material: Table 1) which suggested that discriminant validity problems were not present.

4.3.2. Assessment of the structural model

Assessment of the structural model indicated that there were no collinearity problems as VIF values were below 2 (Meanings = 1.328, Materials = 1.143, Competencies = 1.467). Table 5 shows the path coefficient estimates and confidence intervals of the structural model. The model indicated that having positive meanings of technologies significantly increased the number of calf technologies intended to use on the farm (β= 0.388, CI = 0.291 – 0.486). However, having sufficient materials and competencies did not have a significant effect on the number of calf technologies intended to use on the farm. The R^2 of the structural model was 0.177, which indicated the model's in-sample explanatory power was relatively small. Furthermore, when comparing the predicted errors with a naïve linear regression model (LM) benchmark, the MAE was lower for the LM. This suggests that our model has low predictive power.

4.4. Qualitative comparative analysis

4.4.1. Belgium

The necessary conditions analysis indicated that the presence or absence of the conditions were not necessary for the outcome or negated outcome. This means that none of the conditions (meanings, materials, or competencies) were always present or always absent when the outcome (or negated outcome) was present. The construction of the truth tables for the sufficient conditions analysis showed that there were no sufficient terms for the outcome as the consistency scores for all configurations was < 0.75. Therefore, Belgian dairy farmers' intention to use calf management technologies cannot be consistently explained

Table 4
Metrics to evaluate the construct measures' reliability (Cronbach's α, Rho C, Rho A) and convergent validity (AVE).

	Cronbach's α	Rho C	AVE	Rho A
Meanings	0.828	0.870	0.529	0.862
Materials	0.704	0.866	0.765	0.794
Competencies	0.617	0.784	0.552	0.729

Table 5
Effect sizes and confidence intervals for the structural paths in the PLS-SEM of intention to use calf management technologies.

	Original Est.	Bootstrap Mean	Bootstrap SD	2.5 % CI	97.5 % CI
Meanings->Intention to use technologies	0.388	0.389	0.049	0.291	0.486
Materials->Intention to use technologies	0.008	0.014	0.059	−0.106	0.127
Competencies->Intention to use technologies	0.075	0.082	0.062	−0.039	0.206

Table 3
Mean rating for each of the statements relating to calf management technologies (1 = strongly disagree - 5 = strongly agree, BE = Belgium, NE = Netherlands, NO = Norway, UK = United Kingdom). Asterisk represents significant difference between countries (P < 0.05).

Item	Mean (SE)				
	BE (n = 52)	NE (n = 61)	NO (n = 106)	UK (n = 50)	All (n = 269)
Using calf management technologies is important for the future of my farm*	3.10 (0.16)	2.87 (0.18)	2.67 (0.13)	3.26 (0.14)	2.91 (0.08)
Adoption of calf management technology on farms is expensive	4.02 (0.13)	3.82 (0.15)	4.01 (0.10)	3.80 (0.13)	3.93 (0.06)
Calf management technologies can make my life easier	3.71 (0.14)	3.62 (0.18)	3.32 (0.12)	3.40 (0.10)	3.48 (0.07)
I prefer to work with my calves rather than sitting at a computer	3.73 (0.17)	4.08 (0.14)	4.20 (0.10)	4.00 (0.12)	4.04 (0.06)
Using calf management technologies takes up a lot of time	3.27 (0.13)	2.80 (0.16)	2.88 (0.10)	3.02 (0.12)	2.96 (0.06)
Calf management technologies generate useful outputs*	3.73 (0.13)	4.08 (0.12)	3.43 (0.10)	3.64 (0.08)	3.68 (0.06)
I find calf management technologies difficult to use*	2.94 (0.10)	2.46 (0.13)	2.78 (0.10)	2.64 (0.11)	2.71 (0.06)
It is easier to collect data without using calf management technologies	2.65 (0.14)	2.54 (0.16)	2.76 (0.10)	3.02 (0.14)	2.74 (0.07)
I have the skills required to use calf management technologies	3.77 (0.14)	3.75 (0.16)	3.83 (0.12)	3.84 (0.10)	3.80 (0.7)
Calf management technologies can provide me with a better work-life balance	3.13 (0.14)	3.05 (0.18)	2.89 (0.11)	3.10 (0.13)	3.01 (0.07)
My farm has the appropriate infrastructure (e.g., internet, electricity) for using calf management technologies*	3.74 (0.17)	3.97 (0.16)	4.25 (0.11)	3.44 (0.15)	3.94 (0.07)
I have the support I need to use calf management technologies	3.62 (0.15)	3.66 (0.15)	3.77 (0.11)	3.32 (0.10)	3.63 (0.06)
It is unnecessary for me to use calf management technologies on my farm*	3.56 (0.15)	3.41 (0.19)	3.22 (0.12)	2.82 (0.14)	3.25 (0.08)
Using calf management technologies is boring	2.48 (0.13)	2.48 (0.16)	2.50 (0.11)	2.64 (0.13)	2.51 (0.06)
The size of my farm is not suited towards calf management technologies	3.00 (0.16)	2.92 (0.20)	2.73 (0.13)	3.10 (0.16)	2.89 (0.08)
My farming system is not suited towards calf management technologies*	2.87 (0.17)	2.36 (0.17)	2.74 (0.12)	3.04 (0.14)	2.73 (0.08)
Learning how to use calf management technologies is time consuming*	3.02 (0.12)	2.90 (0.17)	2.57 (0.12)	3.12 (0.12)	2.83 (0.07)

by the conditions of competencies, materials, or meanings. However, there were 7 sufficient terms for the negated outcome (Table 6). This suggests that Belgian dairy farmers' intention to not use calf management technologies can be explained by the conditions of competencies, materials, or meanings.

The truth table for the negated outcome was logically minimised which led to the solution formula:

$\sim$ MEANINGS + $\sim$ MATERIALS + $\sim$ COMPETENCIES → $\sim$ INTTECH

This means that if a Belgian farmer does not have positive meanings OR does not have sufficient materials OR does not have sufficient competencies regarding calf technologies, then this will lead to the outcome of not intending to use calf technologies. The solution coverage was 0.834, which is a measure of how much of the outcome is explained by the solution. Assessment of the robustness showed that the results were robust from both case-oriented and fit-oriented perspectives (Supplementary material: Table 6).

4.4.2. Netherlands

The necessary conditions analysis indicated that the presence or absence of any of the conditions were not necessary for the outcome or negated outcome. This means that none of the conditions (meanings, materials, or competencies) were always present or always absent when the outcome (or negated outcome) was present. The construction of the truth tables for the sufficient conditions analysis showed that there were no sufficient terms for the outcome as the consistency scores for all configurations were < 0.75 (Supplementary material: Table 8). Therefore, Dutch dairy farmers' intention to use calf management technologies cannot be consistently explained by the conditions of competencies, materials, or meanings. However, there were 4 sufficient terms for the negated outcome. This suggested that Dutch dairy farmers' intention to not use calf management technologies can be explained by the meanings condition.

The truth table for the negated outcome was logically minimised which led to the solution formula:

$\sim$ MEANINGS→ $\sim$ INTTECH

This means that if a Dutch farmer does not have positive meanings regarding calf technologies, then this will lead to the outcome of not intending to use calf technologies. In this situation, it is irrelevant if the farmer has appropriate competencies or materials. The solution coverage was 0.562.

Assessment of the robustness showed that there were six farmers who would switch from being a typical (i.e., member of the outcome) or deviant (i.e., not a member of the outcome) case if a different analytical decision was taken. This is because the cases were included in the initial solution but not in the alternate solutions. These are called "shaky" typical and deviant cases.

4.4.3. Norway

The necessary conditions analysis indicated that the presence or absence of the conditions were not necessary for the outcome or negated outcome. There were no solutions in the truth table for the negated outcome. Therefore, Norwegian dairy farmers' intention to not use calf management technologies cannot be consistently explained by the conditions of competencies, materials, or meanings. The construction of the truth table for the outcome showed that there was one solution (Supplementary material: Table 13). Norwegian farmers' intention to use calf management technologies can be explained by the conditions of competencies, materials, and meanings.

The truth table for the outcome was logically minimised which led to the solution formula:

MEANINGS $*$ MATERIALS $*$ COMPETENCIES→INTTECH

This means that if a Norwegian farmer has positive meanings AND sufficient materials AND sufficient competencies regarding calf technologies, then this will lead to the outcome of intending to use calf technologies. The solution coverage was 0.381. Assessment of the robustness showed that the results were robust from both case-oriented and fit-oriented perspectives (Supplementary material: Table 16).

4.4.4. UK

The necessary conditions analysis indicated that the presence or absence of the conditions were not necessary for the outcome or negated outcome. The construction of the truth table for the outcome showed that there were two solutions (Supplementary material: Table 18). The UK dairy farmers' intention to use calf management technologies could be consistently explained by the conditions of competencies and materials. The truth table for the outcome was logically minimised which led to the solution formula:

MEANINGS $*$ COMPETENCIES→INTTECH

This means that if a UK farmer has positive meanings AND sufficient competencies regarding calf technologies, then this will lead to the outcome of intending to use calf technologies. In this situation, whether the farmer had appropriate materials was irrelevant. The solution coverage was 0.533. Assessment of the robustness showed that the results were robust from both case-oriented and fit-oriented perspectives (Supplementary material: Table 22).

The construction of the truth table for the negated outcome showed that there was one solution. The truth table for the negated outcome was logically minimised which led to the solution formula:

$\sim$ MEANINGS $*$ MATERIALS$*$ $\sim$ COMPETENCIES→ $\sim$ INTTECH

This means that if a UK farmer does not have positive meanings AND has sufficient materials AND does not have sufficient competencies regarding calf technologies, then this will lead to the outcome of not intending to use calf technologies. The solution coverage was 0.163.

The assessment of robustness showed that the results were robust from a fit oriented perspective. However, from a case-oriented perspective, the assessment showed that there were nine typical (i.e., member of the outcome) and three deviant (i.e., not a member of the outcome) cases that were not included in the initial solution but were included in at least one of the alternative test solutions. These are called "possible" typical and deviant cases. Inspection of the different test solutions showed that this was because of changes in the cut-off of the raw consistency value. When the cut-off was lowered to 0.7, cases of farmers who do not have positive meanings AND do not sufficient materials AND

Table 6
Belgium truth table for negated outcome (does not intend to use calf technologies).

MEANINGS	MATERIALS	COMPETENCIES	OUTCOME	N	Consistency
0	0	1	1	3	0.953
0	0	0	1	14	0.905
1	0	0	1	7	0.895
0	1	1	1	5	0.867
1	0	1	1	2	0.862
1	1	0	1	6	0.824
0	1	0	1	2	0.822
1	1	1	0	13	0.572

do not have sufficient competencies regarding calf technologies will also lead to the outcome of not intending to use calf technologies.

5. Discussion

This is the first study, to the authors' knowledge, to use a combined PLS-SEM and QCA approach in the veterinary epidemiology field. In particular, we used this PLS-SEM QCA approach to evaluate the application of social practice theory to technology use on farms. Our study was also novel as we specifically focused on the use of calf management technologies and included the perspectives of farmers from four different countries. We assessed whether dairy farmers' intention to use, or not use, calf technologies could be explained by the social practice theory elements of competencies, meanings, and materials. Our results show that the conditions for the intention to use, or not use, calf technologies were different in Belgium, the Netherlands, Norway, and the UK, but the presence (or absence) of positive meanings appeared to be consistently important. In addition, the solutions exhibited equifinality, conjunctural causation, and asymmetric causation, highlighting the causal complexity of technology use on farms as a social phenomenon.

The QCA solution for Norway aligned with our first hypothesis that farmers will intend to use calf technologies if they have sufficient competencies, sufficient materials, and positive meanings towards calf technologies. However, the QCA for the other three countries did not achieve solutions that supported our first hypothesis. A solution for the outcome was not reached for Belgian and Dutch farmers. This could be due to very few of the Belgian and Dutch farmers intending to use a technology for calf management in the next 24 months compared to the Norwegian and UK farmers. Furthermore, there were fewer Belgian and Dutch farmers intending to use technologies in the future compared with currently using technologies. This suggests that some Belgian and Dutch farmers were intending to de-adopt technologies, perhaps because they have had bad experiences.

A solution for the outcome was achieved for the UK farmers; however, it did not align with our hypothesis because sufficient materials was irrelevant to UK farmers' intention to use calf technologies. This is despite the UK farmers appearing to be more negative towards their material situation, such as having the appropriate infrastructure and support, compared to farmers in the other countries (Table 5). This might be because farmers in the UK can utilise government grants to purchase new technologies and improve their infrastructure, which could make them less concerned about having sufficient materials when considering their future use of farm management technologies (Doidge et al., 2024b). However, farmers in Belgium, Netherlands, and Norway may also receive grants for improving infrastructure and therefore this situation is not unique to the UK (Flanders Agency for Agriculture and Sea Fisheries, 2024; Innovasjon Norge, 2024).

The QCA solution for Belgium aligned with our second hypothesis that farmers will not intend to use calf technologies if they do not have the sufficient competencies, or do not have sufficient materials, or do not have positive meanings towards calf technologies. We did not achieve a solution for the negated outcome for Norwegian farmers, which suggests that we need to include different conditions in the model. For example, Norwegian farmers highly value their own experiential knowledge, which can sometimes be a barrier towards technology use (Doidge et al., 2024a), and could be included as a measure in future studies.

The solution achieved for the negated outcome in the Netherlands did not align with the second hypothesis because competencies and materials were irrelevant to Dutch farmers' intention to not use technologies for calf management. The solution achieved for the negated outcome in the UK also did not align with this hypothesis because presence of sufficient materials was required for the intention to not use calf technologies, as opposed to the hypothesised absence of sufficient materials. Assessment of the case-oriented robustness identified that the solutions for the negated outcome for Dutch farmers and UK farmers were not as robust as the other solutions. This was because some of the cases could swap membership in the set if different analytical decisions were made, such as changing the consistency threshold. These results should therefore be interpreted with caution. These inconsistencies might be improved in the future if other conditions were added to the model. In future studies, the farmers representing the inconsistent cases could be interviewed to understand what additional conditions should be added to the model. We were unable to do this in the current study as the respondents were anonymous.

The Norwegian solution was an example of conjunctural causation. In other words, a specific combination of conditions was required to reach the solution. Conjunctural causation would be difficult to interpret in regression analyses because interdependencies are usually modelled as interaction terms (Fainshmidt et al., 2020). Furthermore, the Belgian solution is an example of equifinality as it shows that there are multiple paths to reach the solution. In traditional variable based analyses, such as regression, we would not be able to identify multiple paths and therefore show equifinality. Yet, for evaluating social theories, such as social practice theory, being able to address equifinality or conjunctural causation is important as it allows researchers to test more complex hypotheses. We suggest that use of QCA could be useful for evaluating other theoretical frameworks that are commonly used in veterinary epidemiology and social sciences, such as theory of planned behaviour (Reyneke et al., 2023) or COM-B model (Biesheuvel et al., 2021).

A common condition in all solutions was the presence of positive meanings for the intention to use technologies or the absence of positive meanings for the intention to not use technologies. This suggests that to improve the adoption of technologies for calf management, the positive meanings of the technologies need to be clearly communicated to farmers. The "Meanings" construct that we developed included items that represented several types of meanings, which were identified from a qualitative study (Doidge et al., 2023b). Future studies could investigate which types of meaning are most important for calf technology use or non-use by including additional items and generating sub-scales. Additionally, new items informed by other research on technology adoption could be included in the scale, such as items on good stockperson identity (Kaler and Ruston, 2019), building consumer trust (Schillings et al., 2023), and concerns over data sharing (Brown et al., 2022).

The structural PLS-SEM model showed that having positive meanings about calf technologies was significantly associated with the intention to use calf technologies. This result aligns well with the QCA solutions. However, the QCA provides further information in that the conditions of sufficient materials and/or competencies are required in combination with positive meanings to achieve the outcome. Therefore, in addition to highlighting the positive meanings of technologies, we need to provide farmers with appropriate training, social support, and improve infrastructure to increase uptake of calf management technologies on farms. Some dairy farmers have suggested that training resources such as online video tutorials and educational calf management courses have worked well to improve their use of calf technologies (Doidge et al., 2024a). Furthermore, veterinarians may provide social support to farmers by giving advice on precision livestock technologies and interpretation of data (Giersberg and Meijboom, 2023; Doidge et al., 2024b). It should be noted that the structural assessment of the PLS-SEM showed that the model had low in-sample explanatory power and low predictive power. R^2 is a function of the number of predictor constructs. Therefore, our R^2 may be smaller because we only had three constructs in the model. Despite this, the main reason for conducting PLS-SEM was that we required latent variable scores for the QCA, and evaluation of the measurement model suggested that the latent constructs were suitable. Therefore, they were able to be used in our QCA.

5.1. Study reflections

In this study, we used intention to use calf management technologies as a single outcome. Yet, we acknowledge that use of different technologies will lead to different social practices and thus may have varying materials, meanings, and competencies associated with them. We took this approach because of the relatively low adoption rates of calf management technologies of the surveyed farmers across the countries in this study. However, the study does identify some areas of higher adoption, such as automatic feeders in Norway and weighing scales in the UK, which could be investigated in further detail in future studies.

It is important to note that the study samples from each country were relatively small and not a representative sample. The age and gender distributions differed between countries. However, it was not our aim to generate a representative sample. Instead, our focus was on the reasons for farmers' intention to use calf technologies. Our study sample was large enough to investigate this using both PLS-SEM (Kock and Hadaya, 2018) and QCA methods (Pappas and Woodside, 2021).

The recruitment strategy differed across the countries in terms of method of dissemination to potential respondents, level of reimbursement, and period the survey was open for. This varied approach to recruitment was due to differences in resources in the different countries and initial difficulties recruiting enough respondents. For example, in Norway and Belgium, we had access to mailing lists and could contact farmers directly; however, this was not possible in the UK. We acknowledge that the difference in recruitment strategies between the countries may also contribute to the differences in the QCA solutions.

Although we collected information on farmers' current technology use practices, we chose to use farmers' intention to use calf management technology as the outcome for this study. The reason for this was that attitudes and behaviours are bi-directional, where past behaviours can have an influence on attitudes and vice versa (Doidge et al., 2021). As this was a cross sectional study, the use of the "intention to use technology" outcome allowed us to assume that current attitudes influence future behaviour, as theoretical models often suggest that intentions are an indicator of future behaviour (Biesheuvel et al., 2021). Nonetheless, the study could be improved by using a longitudinal study design.

6. Conclusions

This study used a combined PLS-SEM and QCA approach to understand dairy farmers' intention to use calf management technologies in Belgium, the Netherlands, Norway, and the UK. We aimed to test the hypothesis that farmers will intend to use calf technologies if they have sufficient competencies, sufficient materials, and positive meanings towards calf technologies. Increased positive meanings towards technologies significantly increased the number of calf management technologies that the farmer intended to use. The conditions for the intention to use, or not use, calf technologies were different in Belgium, the Netherlands, Norway, and the UK, but the presence (or absence) of positive meanings appeared to be consistently important. This suggests that to improve the adoption of technologies for calf management, the positive meanings of the technologies need to be clearly communicated to farmers. The study highlighted the usefulness of using QCA for evaluating theoretical hypotheses regarding farmers' behaviour or practices. We suggest that other researchers could use this method to investigate other practices on farms that are thought to have causal complexity.

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CRediT authorship contribution statement

Anouk Veldhuis: Writing – review & editing, Project administration, Investigation, Data curation, Conceptualization. **Inge Santman-Berends:** Writing – review & editing, Project administration, Investigation, Data curation, Conceptualization. **Jasmeet Kaler:** Writing – review & editing, Supervision, Project administration, Methodology, Funding acquisition, Data curation, Conceptualization. **Charlotte Doidge:** Writing – original draft, Visualization, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Noëlle ten Brinke:** Project administration, Investigation, Data curation, Conceptualization. **Jade Bokma:** Writing – review & editing, Supervision, Project administration, Investigation, Data curation, Conceptualization. **Petter Hopp:** Writing – review & editing, Project administration, Investigation, Data curation, Conceptualization. **Luis Pedro Carmo:** Writing – review & editing, Project administration, Data curation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.prevetmed.2025.106417.

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